TIME DOMAIN

THE NEW WIRELESS MEDIUM™

Appendix B

FIELD STRENGTH REQUIREMENTS OF TIME-MODULATED ULTRA-WIDEBAND SYSTEMS FOR VARIOUS APPLICATIONS

Introduction

This appendix focuses on predicting the electric field strength requirements of commercially viable time-modulated ultra-wideband (TM-UWB) systems. The goal of this exercise is to define several applications that would require Class B and Class A field strength limits, and which applications will probably require higher level emissions.

The exercise was initiated by first listing several example applications of TM-UWB and outlining the system specifications required to make them viable products. A link budget analysis was performed for each example in order to estimate the required transmit power. These link budgets account for a wide variety of mechanisms including the nominal effects of the channel for the applicable environment(s), realizable system losses, reliability margin, antenna pattern and gain, required signal-to-noise ratio, etc. After estimating the required transmit power, the electric field strength that would be measured by an average detector is calculated.

This analysis has been tailored for TM-UWB systems with pulse repetition frequencies above 1 MHz, which allows the model to be simplified. First, the average field strength limit will be more restrictive than the peak field strength limit, assuming pulse desensitization will not be applied. Second, the spectrum will appear as random noise uniformly distributed under the spectral envelope; therefore, the devices' transmissions will not have any spectral peaking. Other ultra-wideband systems, such as uncoded impulse radars, direct sequence communication, and frequency agile systems may deviate significantly from these assumptions.

To help summarize the results, Table 1 and Table 2 describe legends that abbreviate the five environments simulated as well as the field strength classification respectively. Table 3 lists communications systems that should be viable under the proposed limits. Similarly, Table 4 lists radar systems that should be viable under the proposed limits.

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#	Environment
1	smooth earth
2	urban
3	obstructed in-building
4	obstructed in-factory
5	dense forestation

Table 1. Environment Legend

Class	Limits (μV/m)
A	300 @ 10 m
B	500 @ 3 m

Table 2. Field Strength Classification Legend

Table 3 shows the predicted field strength classification required for several communications applications. Many applications could be operated in several environments. Additionally, they might be operated as both Class B and Class A devices.

System	Center Frequency (MHz)	Aggregate Bit Rate (kbps)	Desired Range (m)	Environment & Class
Navigational Systems	3000	0.05	100	1-B, 2-B, 3-A, 4-B, 5-B
Mini-Cell RF Asset ID and Tracking	3000	100	25	1-B, 2-A, 4-B, 5-B
Team Comm., ID, and Tracking	2000	64	25	1-B, 2-A, 4-B, 5-B
Music Quality Microphone	2000	500	30	1-B, 4-A, 5-B
Long Range Voice Microphone	2000	64	50	1-B, 4-A, 5-B
Precision Automatic Aircraft Landing System	4500	0.05	3050	1-B
Medical Telemetry	3000	100	40	1-B, 4-A, 5-A

Table 3. Predicted field strength classification for various time-modulated ultra-wideband communications and geo-location system applications.

System	Center Frequency (MHz)	Desired Range (m)	Class
Runway and roadway inspection	4000	1	B
Building Construction Inspection Imaging	8000	1	A
Law Enforcement Agency and Emergency Services motion detection	2000	10	A
Law Enforcement Agency and Emergency Services Motion Detection and Tracking	4000	15	A
Security proximity detector	2000	10	A
Security fence	2000	150	A
Precision airbag deployment sensor	6000	1.5	B
Automotive backup safety sensor	2000	3	B

Table 4. Predicted field strength classification for various time-modulated ultra-wideband radar system applications.

These are but a few applications that have a strong potential to be able to provide commercially viable systems while operating under the proposed Part 15 field strength limits, which are equivalent to the current unintentional digital device radiator limits. There were also several systems simulated that would require higher field strengths. The devices that simulations showed exceeding the proposed limits are: public safety networks, very high speed wireless LAN, wireless business telephone system, ad hoc wide-area network, precision altimeter, obstacle warning for helicopters, airborne SAR mapping, low frequency ground penetrating radar (GPR), and long range automotive collision avoidance. Applications which provide a valuable service, yet require higher emissions levels should be considered for approval on a case by case basis. This evaluation should consider specifics of the technology requesting approval, as well as the environments and restrictions placed on that technology. For example, a fixed industrial wireless LAN may seek approval under a site license, which would restrict the device to that specific location and setup. Another example, is a low frequency UWB GPR, which directs its energy into the ground and has a shielded antenna to minimize radiation leaked into the environment. Furthermore, restrictions may be placed on these devices such that they only be used by a licensed or qualified operator.

Appendix C

Cumulative Impact of Large Numbers of TM-UWB Users

Introduction

An often expressed concern is that large numbers of time modulated ultra-wideband transmitters each emitting a signal that complied with the Part 15 mandated field strength limits might create a situation where the cumulative field strength of the emitters would significantly exceed the field strength limits established by Part 15. This paper examines this issue and by means of a Monte Carlo simulation estimates the impact of increasing densities of time modulated emitters.

Overview

Under special circumstances, the impact on the RF noise floor of numerous co-located Part 15 certified digital devices might be noticeable, e.g., when large numbers of high speed computers are in close proximity (a major brokerage houses can have hundreds of personal computers, workstations, and ancillary equipment all in a single room). Fortunately, propagation losses are significant and even a modest distance between emitters can mitigate the cumulative impact large numbers of users.

Unlike computers, which are often in close proximity when in use, it would be highly unusual for law enforcement officers to be using time modulated radios in extremely close proximity.

This analysis estimates the cumulative field strength of increasingly larger numbers of randomly distributed transmitters. The analytical approach was:

1. Randomly distribute N users over a 100 x 100 meter area (for N = 5 to 100 in steps of 5).

2. Calculate the cumulative field strength of the N users at 81 points within that area, assuming that there is always one transmitter 1 meter from the sample point (which ensures that field strength will be equal to or greater than the field strength of a single transmitter – a worst case assumption). The field strength was calculated assuming a $1/R^2$ propagation path loss and no transmitter could be closer than 1 meter from the measurement point.

3. Repeat step (2) 1000 times for different random distributions of N users.

4. Calculate the mean value of the RMS field strength at the 81 sample points for all 1000 Monte Carlo simulations, i.e., average over 81,000 samples. Also, for each of the 1000 random distributions, select the largest RMS value from the 81 sampling points, then determine the average value of these 1,000 samples.

Figure 1 shows graphically the area over which simulated emitters were distributed and the area within which the simulated field strength was calculated.

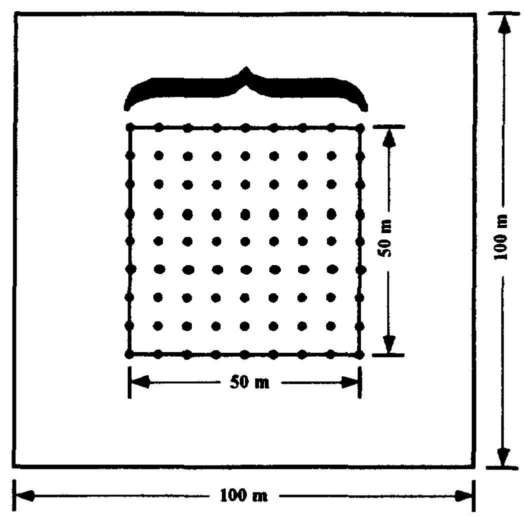


Figure 1. Graphical depiction of simulated operational area.

As shown in Figure 1, the sample points are distributed over the central area (50 m x 50 m) of the simulated operating area. This was done because with a uniform distribution of emitters over the 100 m x 100 m area, the greatest impact of large numbers of simultaneous emitters would probably be within this central area.

Results

Figure 2 shows the resulting values from the simulation. The results show the significant impact of propagation losses on the cumulative field strength of multiple users. Even with 100 users distributed over the 100 by 100 meter area, the RMS value of the field strength at the 81 measurement points is up only 1.2 dB over the field strength contributed by a single user and the RMS of maximum values is up less than 6 dB.

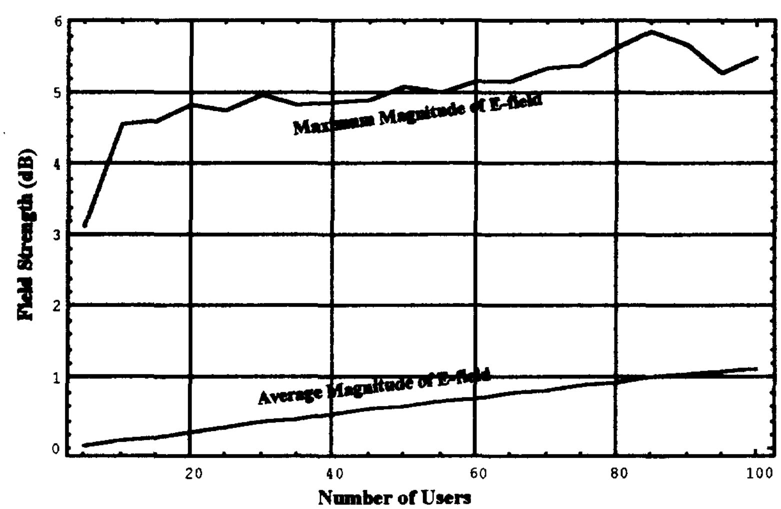


Figure 2. Simulation results: RMS and Maximum RMS field strength values.

Assuming that for every transmitter there is at least one receiver, then 100 emitters within a 100 m x 100 m area implies there are at least 200 people in an area about the size of a baseball field and on average there would be at least two emergency services personnel within each 10 m x 10 m area. Such a high concentration of emergency services personnel would probably be physically difficult to make covert, rendering the need for a covert RF communication capability a moot point.

Conclusions

Even in the worst case, the cumulative field strength of multiple simultaneous time modulated users would be a small increase over the contribution of a single user.

Appendix D

Impact of Notch Filters on UWB Signals

A requirement to attenuate those portions of the emissions of ultra-wideband (UWB) signals that fall in the restricted bands implies a requirement to use notch filters. Unfortunately, notch filters would be highly disruptive and would destroy information contained in the pulse shape. Both communications and radar systems would suffer losses greater than implied by the fraction of spectrum loss. Communications systems would lose immunity to multipath and radar systems would loose resolution in ways that cannot be recovered by additional signal processing.

Notch filters disrupt impulse signals by two mechanisms: spectral power loss and time dispersion. Spectral power loss is the loss of power due to the frequency domain transfer function of the filter. This results directly in power lost to the transmitted waveform, because the power is limited by spectral density rather than total power. In a typical UWB occupied bandwidth, the restricted bands may be 25% or more of the spectrum available. This results in a loss of at least 25% of the power that would otherwise be available.

A realizable filter will also have loss in the skirts surrounding the intended restricted bands. In addition, this filter will have some insertion loss, which will impact input power requirements and cost of the device. Because of the skirt rejection, typically much more energy is removed than is indicated by the restricted band fraction of bandwidth. Filters can be made sharper, but this requires more poles, higher Q, larger components, and greater stability. This results in a further distortion of the waveform, as well as, a larger, higher cost product.

Time dispersion of the pulse waveform is a second mechanism of signal disruption. Time dispersion is the spreading of the pass band energy over a much longer time interval than the original pulse input. The spreading results from the complex high-Q ringing modes of the filter tuned circuits, causing the signal to ring for many cycles after the original pulse. Since typical time modulated ultra-wideband (TM-UWB) correlators - especially those used in low cost devices - operate by correlating for only one cycle, this spreading of the energy over several cycles results in significant energy loss. In fact, this energy loss may often be greater than the attenuation from the notched bands.

To clearly illustrate the effect of filters on TM-UWB waveforms, several filters were tested with a typical UWB pulse generator to show the effects. These filters included two stub filters designed for PCS at 1.9GHz and 1.74 GHz, and a dual notch GPS filter which included a high pass function. The GPS notch filter is a single device that has stop bands for both military and civilian GPS bands, along with a high pass filter function. The 1.74 GHz stub filter has a stopband at 1.74 GHz. The PCS stub filter has a stopband at 1.9

GHz, which is the PCS cellphone band. Each filter was tested individually and then the three were combined.

The data is presented in three plots: 1) time domain response, 2) frequency domain spectral response, and 3) time domain integrated energy plot.

The Filter Responses

The time domain responses are the result of a high speed digital sampling scope collecting a quasi-impulse response of a filter representing the effects of an antenna and a TM-UWB radio's transmitter. Figure 1 shows the UWB signal used to excite the filters. This signal is the output of an antenna emulator network fed by an impulse generator. The antenna emulator network provides the equivalent response of a transmit and receive antenna in a fully cabled test setup. The use of an actual pair of antennas would introduce room impulse response echoes that would confuse the result.

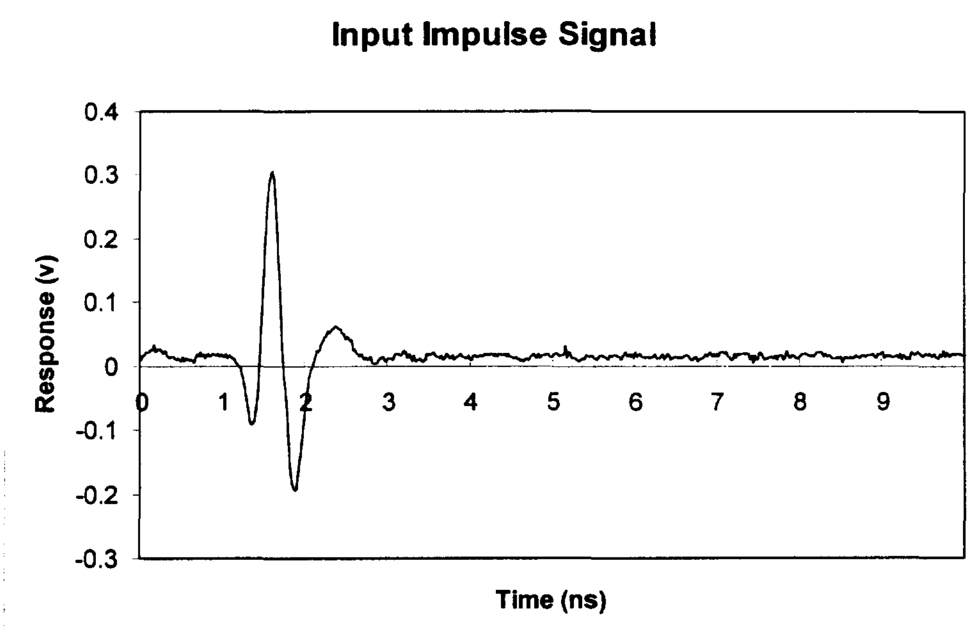
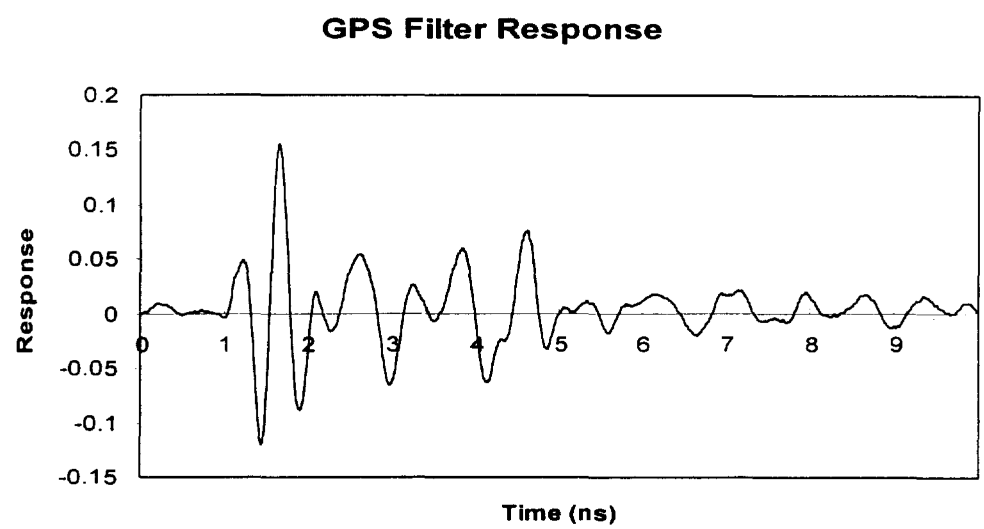


Figure 1. Time domain response of antenna emulator filter. This represents the signal used to excite the filters under test.

The series of plots that follow are paired to present the time domain response then the frequency domain response for each of the four filter configurations.

The time domain response plots show how the energy is spread over an interval containing many cycles of the waveform. Note that the cycles are not uniform due to the frequency dispersion of the filters. This spreading over time is the process that compromises performance and complicates receiver design.

The frequency domain spectral response plots are the result of sweeping each filter with the spectrum analyzer and tracking generator. In the case of the combined filters, 7dB attenuation was used between the filters to reduce interaction between the filters.



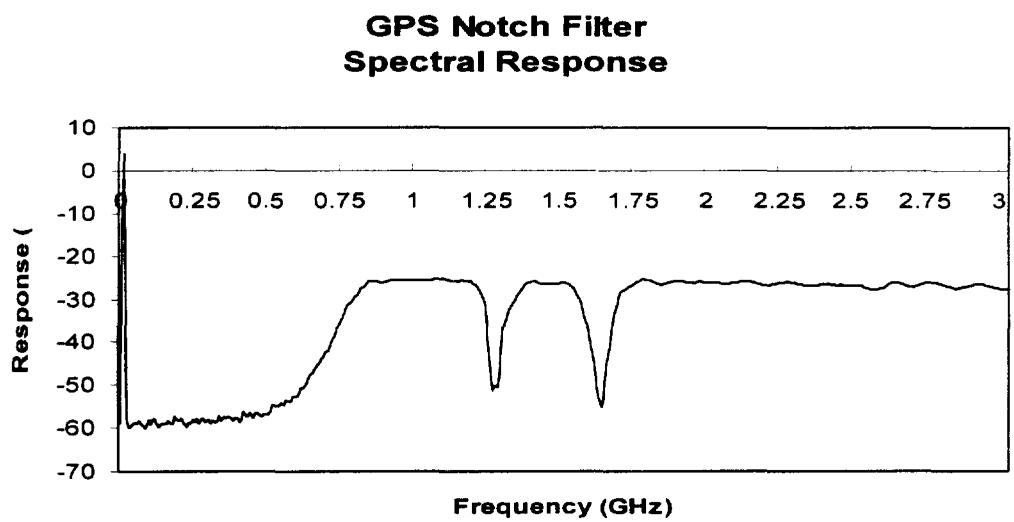
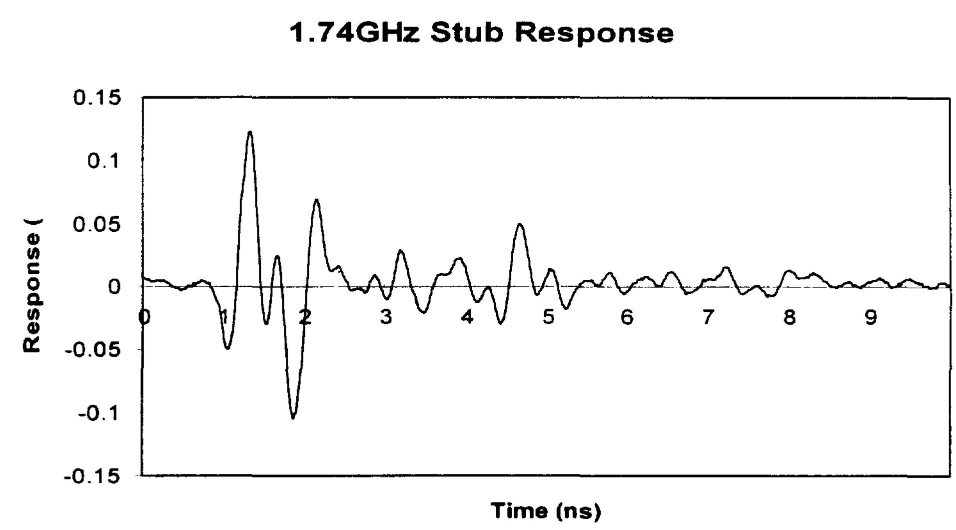


Figure 2. Time domain and frequency domain responses from GPS notch filter.



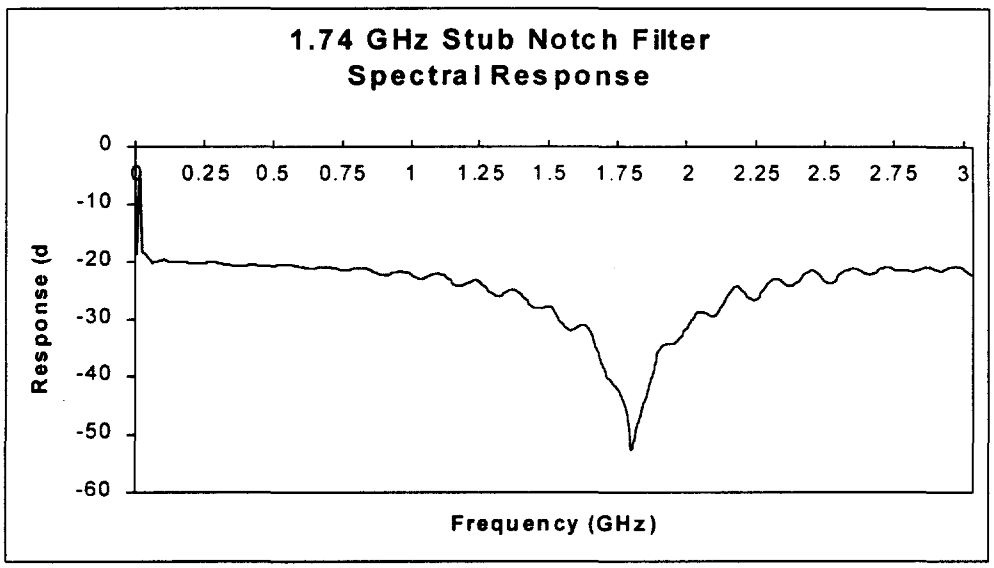


Figure 3. Time domain and frequency domain responses from 1.74 GHz stub filter.

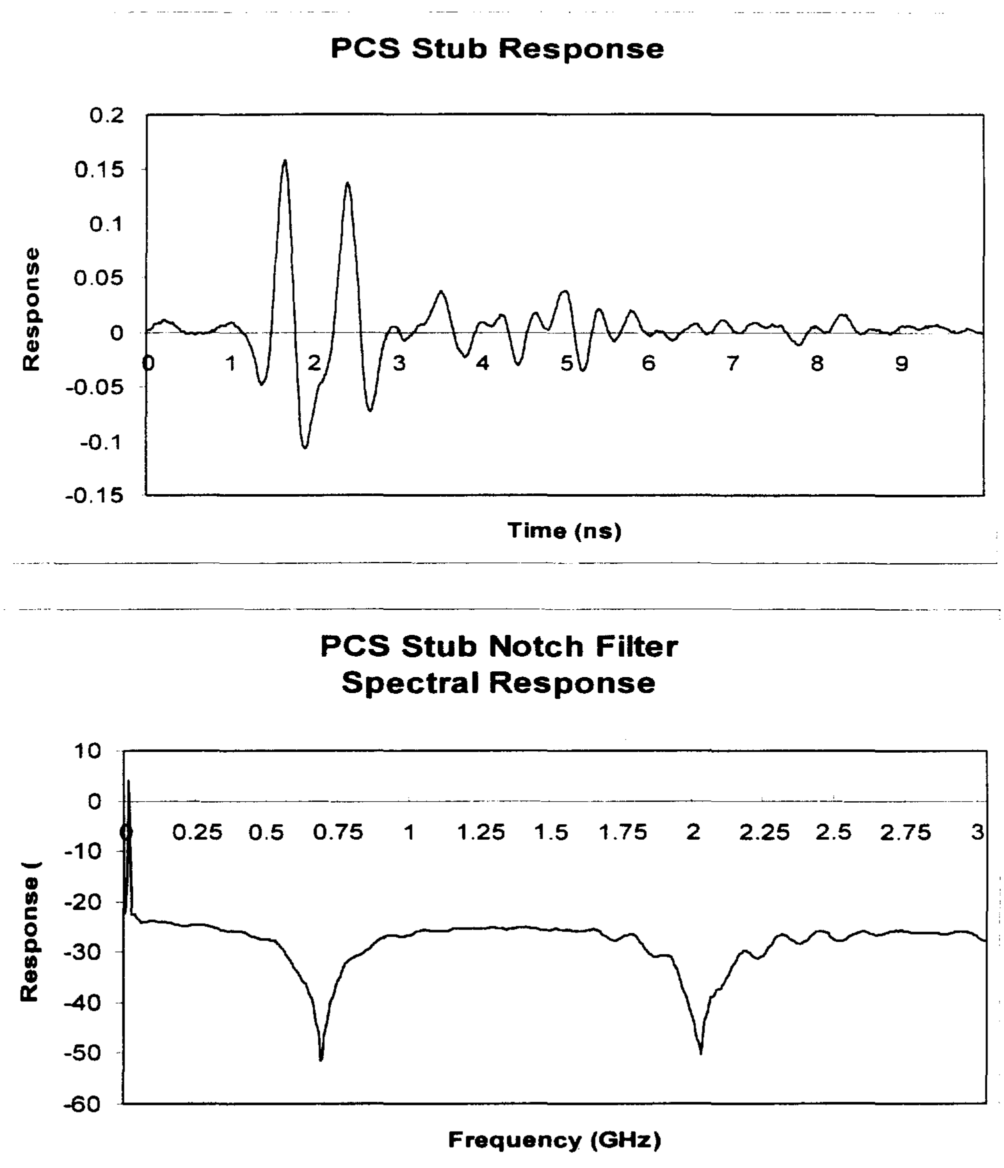
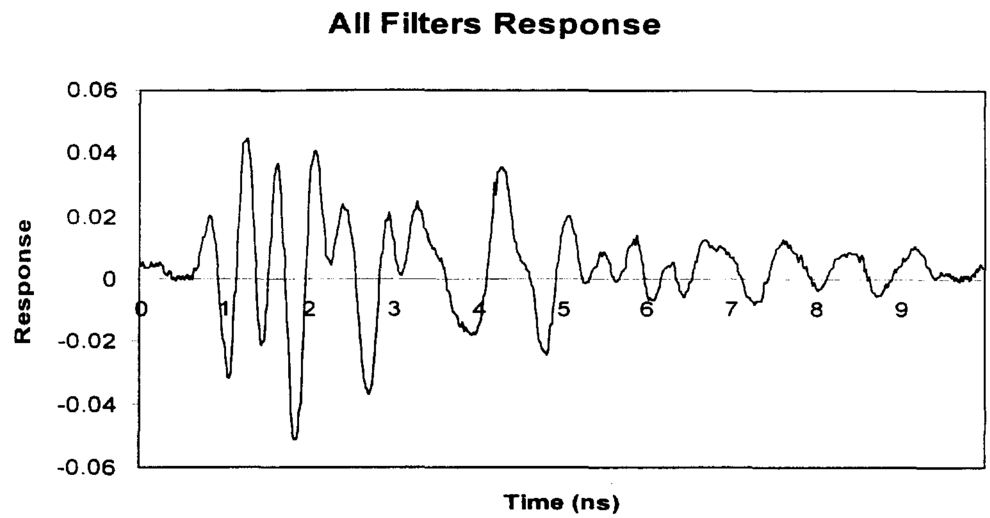


Figure 4. Time domain and frequency domain responses from PCS stub filter.



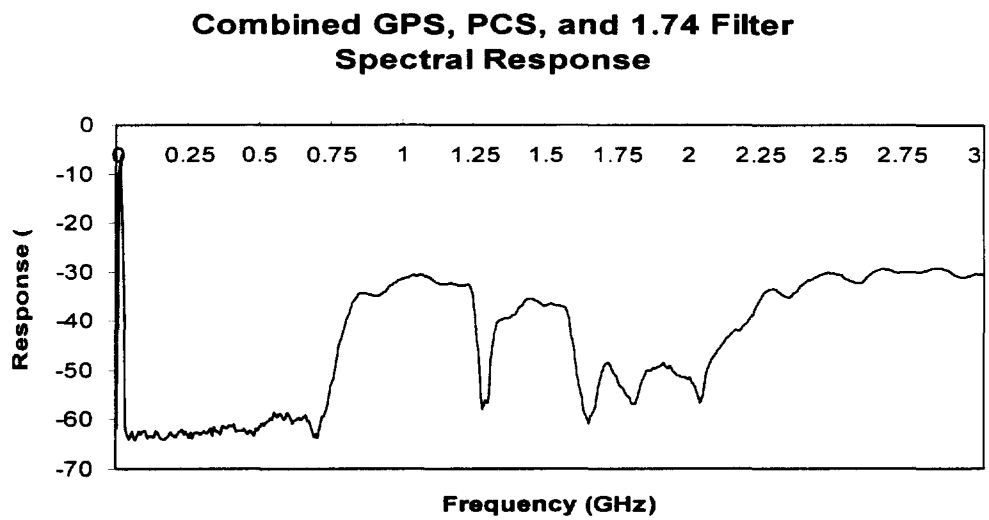


Figure 5. Time domain and frequency domain responses from the composite of the GPS notch, 1.74GHz stub, and PCS stub filters.

The Integrated Energy

The integrated energy graph helps assess the fraction of total energy in each cycle of the voltage response waveform. In Figure 6, for example, it can be seen that the largest cycle contains nearly 90% of the total energy; whereas, Figure 7 indicates only 45% is available in the largest cycle. This represents a 3 dB loss due to energy spreading in time, in addition to energy loss due to the frequency domain energy rejection property of this GPS notch filter.

The integrated energy response was calculated by:

$$E_n(t) = \frac{\int_0^t (v(\tau) - v_{ave})^2 \, d\tau}{E_t}$$

Where,

E_n is the normalized integrated energy,
v is the voltage response value
v_{ave} is the average voltage over the data set, the DC value
E_t is the final value of the energy integral over the data set. This is used to normalize the plot.

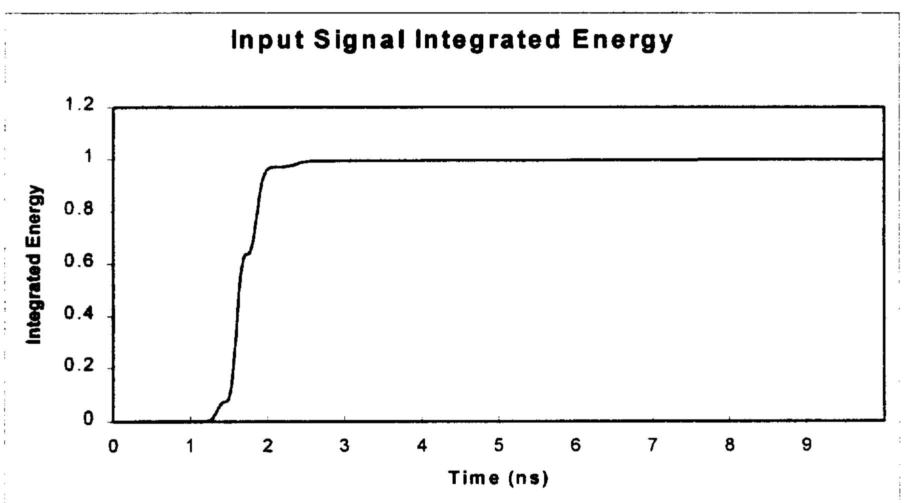


Figure 6. Time domain integrated energy plot of antenna emulator filter. This represents the performance without imposing notch filters.

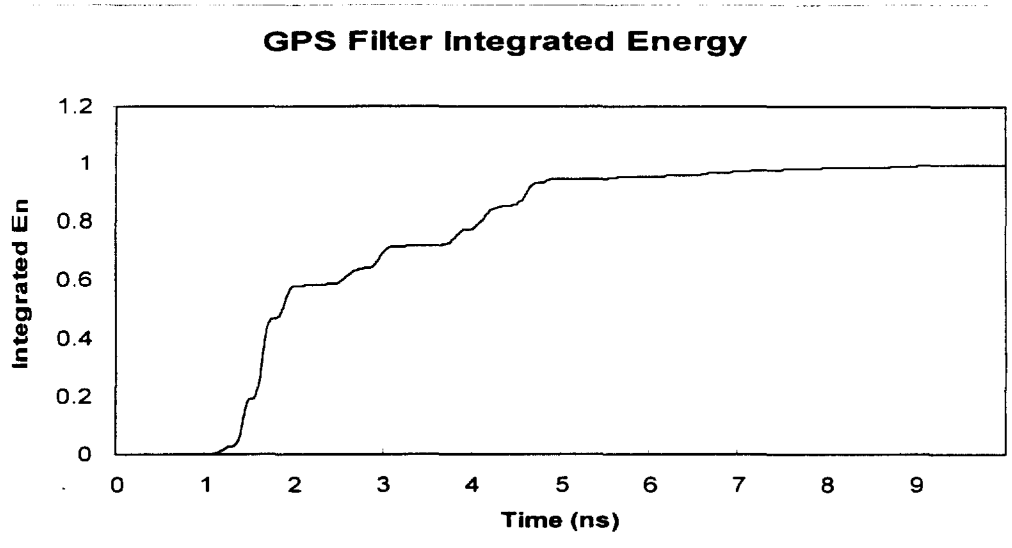


Figure 7 Time domain integrated energy from GPS notch filter.

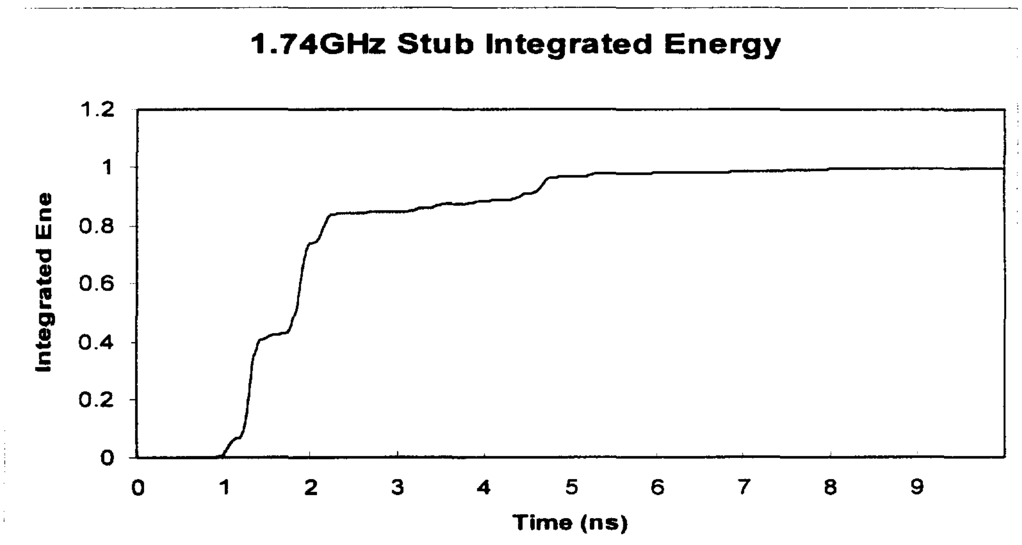


Figure 8. Time domain integrated energy from 1.74 GHz stub filter.

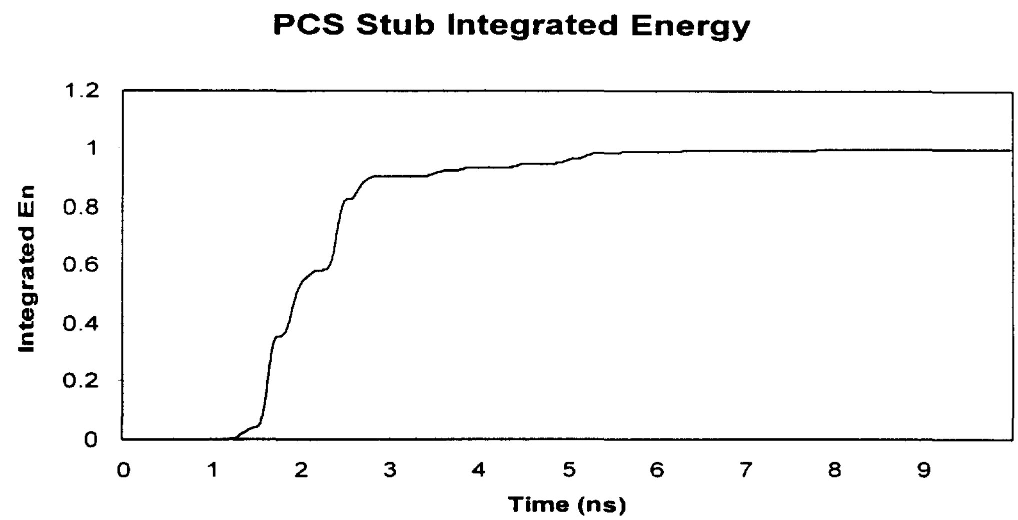


Figure 9. Time domain integrated energy from PCS stub filter.

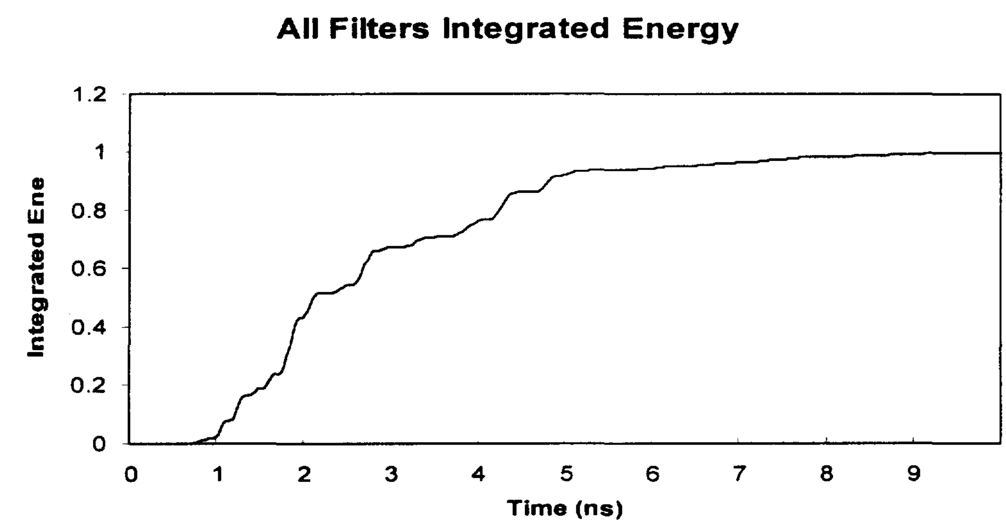


Figure 10. Time domain integrated energy from the composite of the GPS notch, 1.74GHz stub, and PCS stub filters.

Conclusion

Notch filters will degrade communications, positioning, and radar systems be means of removing power and time dispersion of the UWB waveform. Communications links will not only have a decreased signal-to-noise ratio, but will also have reduced channelization, multipath immunity, and jamming resistance. In addition, ranging and positioning systems will also have ambiguities in determining the first arriving signal associated with the direct path. Radar systems will be impaired even further than communications links. The distorted pulse that is a product of notch filters will degrade the range resolution of UWB radars, as well as produce sidelobes that inhibit processes like imaging and object identification. Further, notch filters would increase the size, cost, and complexity of UWB systems. All of the above factors would negatively impact the commercial viability of UWB technologies and products.

For the unique and beneficial applications that only UWB technologies can offer, the vital attribute that allows for these is the clean very short pulse. Anything added to the transmission line that modifies this waveform, such as a notch filter, will diminish sensitivity, reduce resolution, and increase cost. It is thus Time Domain's recommendation that the FCC allow UWB emissions to fall within the restricted bands in order to bring the full benefits of this technology to the commercial and consumer users.

Appendix E

INAPPLICABILITY OF PULSE DESENSTIZATION TO TIME-MODULATED ULTRA-WIDEBAND EMISSIONS

INTRODUCTION

The FCC employs three mechanisms for controlling the peak envelope power from intentional radiators under Part 15. The first mechanism is a measurement technique by employing a peak detector on a spectrum analyzer. The second is another measurement mechanism that numerically adjusts the peak detector measurement for pulse desensitization. The final mechanism is a simple criteria by setting a peak field strength limit.

Time Domain Corporation (TDC) concurs with the FCC that the peak detector measurement and limits on the peak emissions should be in place. However, TDC maintains that applying pulse desensitization to time-modulated ultra-wideband (TM-UWB) intentional radiators unfairly penalizes the technology, and inaccurately assesses the potential for interference.

The following briefly discusses the current FCC rules, gives a background on peak detectors and pulse desensitization, and why pulse desensitization is not only erroneous but deviates from the original intention.

THE REGULATIONS

The regulations are very clear regarding the field strengths for both average detector and peak detector measurements for frequencies above 1000 MHz.

> On any frequency or frequencies above 1000 MHz, the radiated limits shown are based on the use of measurement instrumentation employing an average detector function. When average radiated emission measurements are specified in the regulations, including emission measurements below 1000 MHz, there is also a limit on the radio frequency emissions, as measured using instrumentation with a peak detector function, corresponding to 20 dB above the maximum

> permitted average limit for the frequencies being investigated. CFR 47 (1)

There are additional restrictions on these measurements.

> When the radiated emission limits are expressed in terms of the average value of the emission, and pulsed operation is employed, the measured field strength shall be determined by averaging over one complete pulse train, including blanking intervals, as long as the pulse train does not exceed 0.1 seconds. CFR 47 (2)

Therefore, submissions must include measurements of the emissions for frequencies above 1000 MHz using both an average detector and a peak detector. Since Time Domain Corporation's systems use pulse repetition frequencies (PRF's) in excess of 1 MHz, emissions measured at 3 meters, for frequencies above 1000 MHz, using an average detector, must not exceed 500 uV/m, and emissions measured using a peak detector, must not exceed 5000 uV/m (3). For emissions below 1000 MHz, a quasi-peak detector with the appropriate bandwidth setting is used.

The regulations stipulate when the measurements need to be adjusted for pulse desensitization.

> Note: For pulse modulated devices with a pulse repetition frequency of 20 Hz or less and for which CISPR quasi-peak measurements are specified, compliance with the regulations shall be demonstrated using measuring equipment employing a peak detector function, properly adjusted for such factors as pulse desensitization, using the same measurement bandwidths that are indicated for CISPR quasi-peak measurements. CFR 47 (4)

Since Time Domain Corporation's systems use pulses with nominal PRF's greater than 1 MHz, the measurements do not need to be adjusted for pulse desensitization according to CFR 47. At this point, it should be noted that the application of pulse desensitization is an interpretation to the rules as opposed to the letter of the rules.

AVERAGE DETECTORS AND PEAK DETECTORS

The following summary of what average detectors and peak detectors are may help explain the significance of the emission measurement techniques, and aid in understanding pulse desensitization. A typical spectrum analyzer is a superhetrodyne receiver with a sweeping local oscillator as illustrated in Figure 1. The IF amplifier filter determines the resolution bandwidth. The signal from the final IF amplifier circuit is detected. A low pass filter, which defines the video bandwidth, filters the output from the detector. The instrument then displays the results. Note that digital analyzers digitize the output of the detector and may perform a variety of operations beyond the low pass video filter.

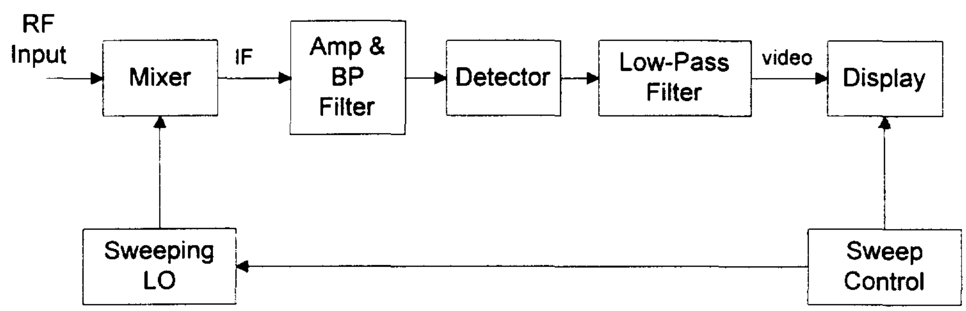


Figure 1. Conceptual block diagram of a typical spectrum analyzer.

Many spectrum analyzers have a preset function using a peak detector mode. The peak detector refers to the use of a peak envelope detector. The analyzer reduces the detected voltage value by a factor of $\sqrt{2}$ to convert the signal to root-mean-square (RMS) voltage and calculates the average power on the assumption the signal is a sinewave. Because spectrum analyzers treat all signals as if they are sinewaves, they introduce some errors, such as this peak to RMS calibration and power conversion for non-sinusoidal signals. Because of the sweep time, frequency span, and filter settings, digital analyzers collect multiple samples at a single frequency. The peak detector mode will select the sample with the largest value for that specific frequency and neglect the rest of the samples.

The description of an average detector is more difficult because there are a number of ways a spectrum analyzer can implement an average detector. Hewlett Packard provides the following description (5):

> Average detection weights a signal level based on the repetition frequency of the spectral components making up the signal. In other words, both peak and average detection will yield the same amplitude values for a CW signal. A periodic, broadband, or impulsive signal will yield an average level lower than the peak value.

The average detector performs this weighting by many different techniques, ranging from collecting in a single sample mode and minimizing the video bandwidth to performing averaging in place. Fortunately, any of these techniques are adequate to perform the measurements. Again, the analyzer reduces this value by a factor of $\sqrt{2}$ to convert the detected value to its equivalent RMS voltage then to average power on the assumption the signal is a sinewave.

PULSE DESENSITIZATION

"Pulse desensitization" is somewhat of a misnomer because the sensitivity of the spectrum analyzer is not reduced by pulsed emissions. It is really the apparent reduction in amplitude of a pulse modulated sinusoid compared with the unmodulated carrier signal when measured with a peak detector. This reduction in amplitude is caused by a combination of the measurement device intercepting a smaller band of signal than is radiated and the response of circuits within the measurement equipment. Note that average detector measurements will also show a reduction due to the duty cycle of the signal.

Pulse desensitization was developed to analyze uniform pulse modulated carriers similar to that shown in Figure 2. This example has a 2.048 GHz carrier modulated by a 7.8125 ns pulse every 100 ns. To help facilitate the discussion, the discrete Fourier transform of this pulsed sinusoid is shown in Figure 3. The resultant from measurements depend upon whether the signal was measured by equipment using a peak detector with a resolution bandwidth (RBW) less than or greater than the pulse repetition rate (PRF). When the RBW is less than the PRF, the individual line spectra are observed but, when RBW is greater than the PRF, a dense continuous spectrum is observed. The observed signals for both cases are described by Table 1. These equations will yield 1% or less error as long the pulse contains fifteen or more cycles.

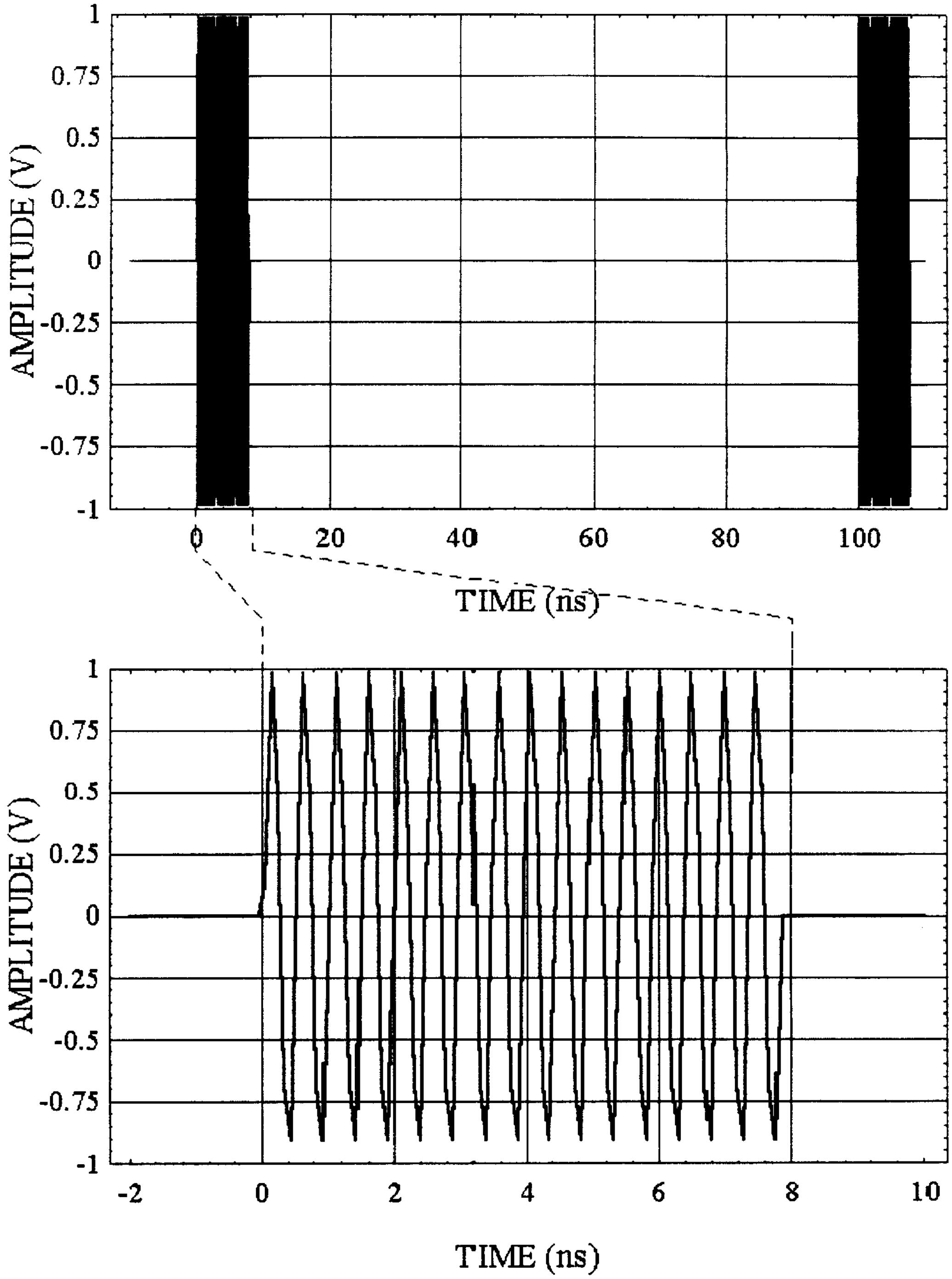


Figure 2. Example of pulsed sinusoid waveform.

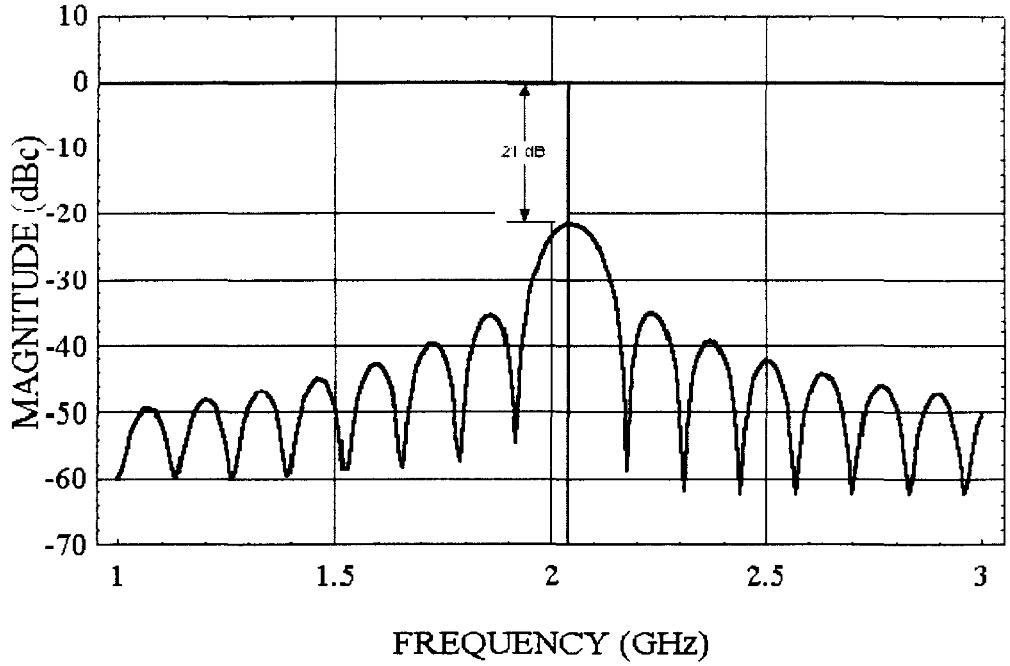


Figure 3. Fourier transform of unmodulated carrier and of pulsed sinusoid.

RBW < 0.3 PRF	Discrete Line Spectrum (V_{rms})	$C_n = \frac{A\,t_0}{\sqrt{2}\,T}\frac{\sin\left(\frac{n\,\pi\,t_0}{T}\right)}{\left(\frac{n\,\pi\,t_0}{T}\right)}$
PRF < RBW < $\frac{0.2}{t_0}$	Dense Continuous Spectrum ($V_{rms}/Hz_{impulse\ bandwidth}$)	$S(\omega) = \frac{A\,t_0\,B_i}{\sqrt{2}}\frac{\sin(\pi\,t_0\,(f-f_0))}{\pi\,t_0\,(f-f_0)}$

Table 1. Observed spectral relationships for pulsed sinusoids, where: A - amplitude of carrier, T - period (1/PRF), t_0 - rectanglular pulse width, f_0 - carrier frequency (6).

Pulse desensitization is calculated by dividing the maximum of the weightings in Table 1 by the RMS amplitude of the unmodulated carrier, $A/\sqrt{2}$. The resulting pulse desensitization factors are given in Equation 1 and Equation 2 (7). An interpretation of these equations is that all of the components intercepted add coherently, so they add in terms of voltage, thus explaining the *20 Log* relationship. The reason there must be two equations is that when the RBW is less than the PRF, only one spectral line is intercepted so the perceived signal is independent of the RBW as long as it stays less than the PRF. When the RBW is greater than the PRF, it can be approximated as a continuous spectrum, so the perceived signal is related to the ratio of the intercept bandwidth to the emissions bandwidth. These equations are generally used to determine pulse desensitization and provide a means to calculate the peak envelope power (PEP), which is the average power during the pulse of a uniform rectangular pulse modulated sinusoid whose pulse width contains at least 15 cycles of the carrier. A peak detector measurement will yield the PEP only when the impulse bandwidth of the measurement equipment exceeds the bandwidth of the pulsed sinusoid emissions. Also note that the PEP is sometimes referred to as peak power but should not be confused with other definitions of peak power.

$$\alpha_L[dB] = -20\log_{10}\left(\frac{\tau_{eff}}{T}\right)$$

where,
α_P - pulse desensitization,
τ_{eff} - effective pulse width,
T - pulse period

Equation 1

$$\alpha_P[dB] = -20\log_{10}(t_0\ B_i)$$

where,
α_P - pulse desensitization for pulse spectrum,
t_0 - rectangular pulse width,
B_i - impulse bandwidth of instrument

Equation 2

TM-UWB EMISSIONS

TM-UWB emissions are necessarily noise-like and non-sinusoidal. Without these attributes, the technology probably would not have sufficient processing gain to allow it to share spectrum with other RF systems. TM-UWB emissions are very definitely not the pulsed sinusoid waveforms assumed in the HP application notes. In many respects, this superior spectrum sharing characteristic is the same characteristic that makes measuring the emissions complicated. TM-UWB emissions are:

- Composed of series of very short signals generally similar to the one illustrated in Figure 4. Clearly there are fewer than the 15 cycles required for application of pulse desensitization. This short duration signal spreads its energy over a very, very large bandwidth. (Note: It is possible to generate TM-UWB waveforms with more zero crossings. Such waveforms would have less bandwidth than the waveform shown in Figure 4.)
- "Carrier-free" signals. There is no modulated carrier signal (8). Each pulse is identical in shape, yet each pulse's time position is either randomly or pseudo-randomly determined and independent in time of any of the other pulses. The random or pseudo-random time modulation makes the signal noise-like, particularly to devices with smaller bandwidths.
- Noise-like in both time and frequency domains, i.e., at the standard measurement distance the TM-UWB signal is similar to ambient and thermal noise.

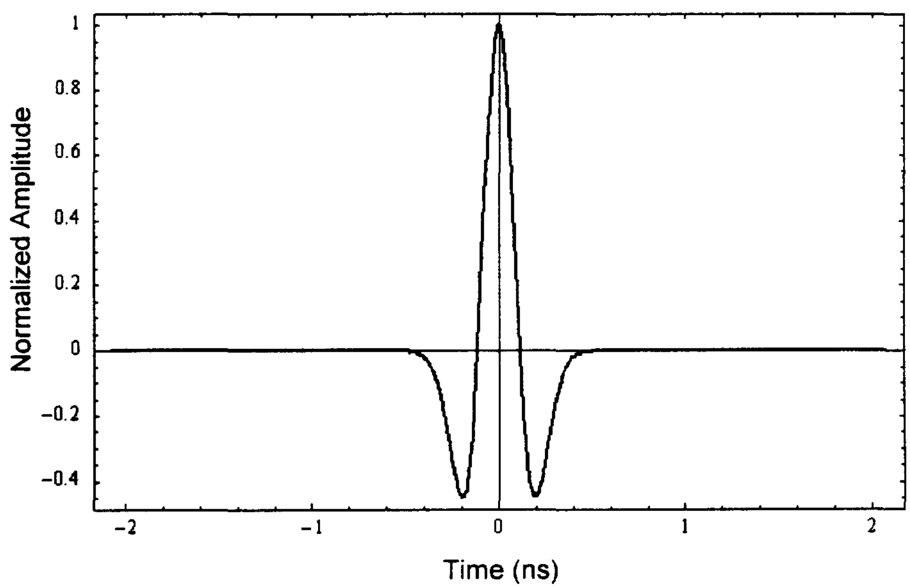


Figure 4. An example of a single TM-UWB waveform.

The noise-like nature of the signal is emphasized by comparing it to the emissions from an unintentional radiator. Such an emission is shown in Figure 5 from a digital device, except Time Domain's random/pseudo-random time modulation ensures its emissions are decorrelated and even more noise-like.

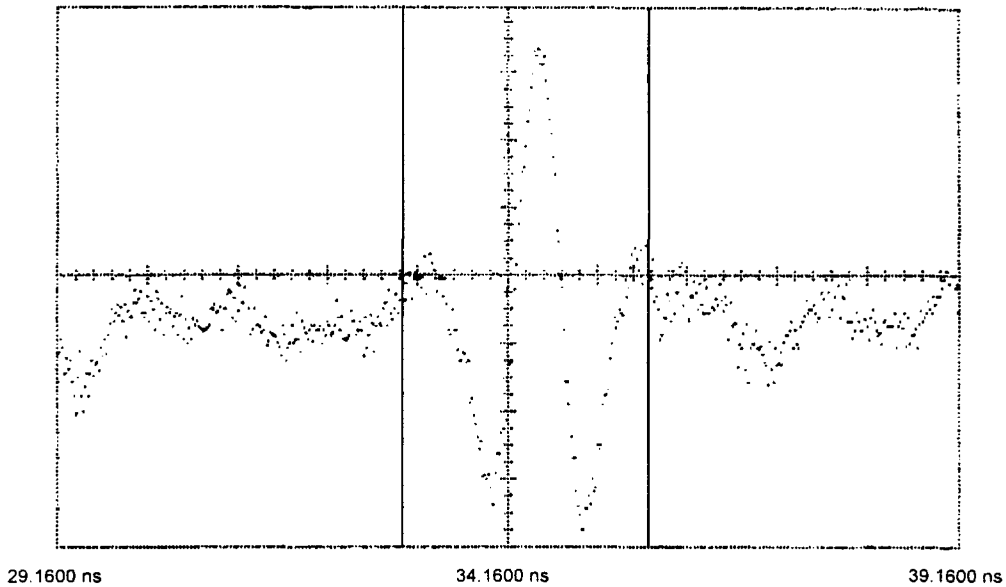


Figure 5 Emission from Pentium personal computer motherboard. Note the ultra-wideband waveform within the vertical lines that strongly resembles the waveform in Figure 4.

The bandwidth of Time Domain's systems also presents a different aspect in terms of the potential harmful interference. The definition of an ultra-wideband signal is that it has greater than 25% relative bandwidth (9). The bandwidths of Time Domain's systems are generally greater than 60%. It is very improbable that any existing victim receiver would have a bandwidth comparable to a TM-UWB transmission (which in practice generally exceeds 1 GHz). If there were such a system, it would most likely be a spread spectrum system or possibly another TM-UWB system. Such systems depend on processing gain to allow spectrum sharing. Such spread spectrum systems would "despread" the intercepted signals to lower its impact. This despreading enables spread spectrum systems to occupy bandwidths simultaneously with licensed users and other services that transmit several orders of magnitude more power than Time Domain's proposed systems.

The differences between a pulsed sinusoid and Time Domain's TM-UWB emissions are summarized in Table 2.

TM-UWB Emissions	Pulsed Sinusoid
HP App. Note 150-2 is not applicable	HP App. Note 150-2 is applicable
Carrier Free	Pulse modulated sinewave carrier
"W" or many fewer than 14 cycles	Duration > 14 Cycles
Relative Bandwidth 25%	Relative Bandwidth < 8%
Asymmetric Spectrum	Symmetric Spectrum
Noise Encoded Time Modulation	Uniform Pulse Train
Noise-Like Spectrum	Spectrum Occurs in Harmonics

Table 2. Comparison of pulsed sinusoid to Time Domain's time-modulated ultra-wideband pulses.

CONCLUSION

It has been shown that pulse desensitization equations are not accurate, but more importantly, unfairly penalize TM-UWB systems in terms of estimating interference potential. Such a penalty would greatly hinder the potential viability of TM-UWB systems. Forcing the peak detector measurement of TM-UWB systems to be adjusted to represent a receiver with a bandwidth comparable to the TM-UWB transmitter's, without taking into account unintentional radiators, licensed radiators, and other devices most likely emitting higher peak power levels, is incorrect and unnecessary. This approach would be inconsistent and does not suit the spirit of the law. TDC recommends that the standard peak detector and peak limits be used without adjusting for pulse desensitization.

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1 Code of Federal Regulations 47, Parts 0 to 19, Telecommunications, Washington, D.C., the Office of the Federal Register National Archives and Records Administration, 10/1/94, §15.35(b).

2 Ibid., §15.35(c).

3 Ibid., §15.109 and §15.209.

4 Code of Federal Regulations 47, Parts 0 to 19, Telecommunications, Washington, D.C., the Office of the Federal Register National Archives and Records Administration, 10/1/94, §15.35(a).

5 Hewlett-Packard, HP85712D EMC Personality HP 84100B/110B AMC Systems User's Guide, California, Hewlett-Packard Co., 1992, p. 3-163.

6 Engelson, M., Modern Spectrum Analyzer Theory and Applications, Dedham, Massachusetts, Artech House, Inc., 1984, p. 149 - 154.

7 Spectrum Analyzer Series, Application Note 150-2, Spectrum Analysis .... Pulsed RF, Hewlett Packard, November 1971, p. 7 and 14.

8 Moe Z. Win and R.A. Scholtz, *Comparison of Analog and Digital Impulse Radio for Wireless Multiple Access Communications*, Submitted to IEEE Transactions on Communications.(A copy of the draft article is attached to this memorandum.)

9 *Introduction to Ultra-Wideband Radar Systems*, Edited by James Taylor, CRC Press, Ann Arbor, 1995 and OSD/DARPA, Ultra-Wideband Radar Review Panel, *Assessment of Ultra-Wideband (UWB) Technology*, DARPA, Arlington, VA, 1990.

TIME DOMAIN

THE NEW WIRELESS MEDIUM

Appendix F

Measurement of the Impact of TM-UWB Emissions on Wideband Low Noise Amplifiers

Purpose

This experiment demonstrates that the instantaneous peak of the emissions from Time Domain Corporation's (TDC) time modulated ultra-wideband (TM-UWB) system operating under FCC Part-15 regulations does not cause amplifiers of wide or ultra-wideband receivers to become non-linear.

Background

The FCC defines limits for the peak-envelop-power for Part 15 operation. The FCC's current interpretation of the rules has the caveat that intentional radiators emitting pulses must also adjust for pulse desensitization using a specific set of equations[1]. These equations for pulse desensitization are only applicable to uniform pulse modulated sinusoids with a pulse width greater than fourteen carrier cycles. Time Domain contends that adjusting TM-UWB systems' emission measurements for pulse desensitization as described in the regulation references is erroneous and inconsistent and does not achieve the goal of predicting the potential for harmful interference.

Time Domain demonstrates that adjusting for pulse desensitization is unnecessary. In preparation of the paper titled, "Part 15 Emissions Measurement Technique for TM-UWB Signals" (submitted as Appendix B of Time Domain's Waiver Request filed February 2, 1998), Time Domain staff conferred with Morris Engelson, a former Director of Spectrum Analyzer Development at Tektronix and noted authority on EMI, and with representatives of Tektronix. Engelson concurred that the best method for measuring TM-UWB emissions is to treat them as if they were generalized EMI signals and not to adjust for pulse desensitization. He also suggested demonstrating that our peak-envelop-power was not harmful, TDC should demonstrate the linearity of an amplifier with and without the presence of TM-UWB emissions.

Equipment

A list of the equipment used is provided in Table 1. All of these devices were readily available in TDC's laboratory. The power meter and 1 GHz high pass filter were used strictly for measuring the transmit power from the two TM-UWB transmitters.

[1] Spectrum Analyzer Series, Application Note 150-2, Spectrum Analysis .... Pulsed RF, Hewlett Packard, November 1971.

Description	Make and Model
sinewave generator	HP 8595 tracking generator
3 dB fixed attenuator	M/A-Com 2082-6141-03
1 dB/step variable attenuator	HP 8494D
10 dB/step variable attenuator	HP 8495D
UWB dipoles (qty 2)	Time Domain 1.3 GHz UWB dipoles
TM-UWB transmitter	Time Domain 3002-1 Gemini Radio
horn antenna	Electro-Metrics RGA-30
low noise amplifier (trial #1)	HP 8447D
low noise amplifier (trial #2)	Miteq AMF-2D-005060-18-13P
low noise amplifier (trial #3)	Miteq AFS3-00100400-28-10P-4
spectrum analyzer	HP 8590B
power meter	HP 437B
1 GHz high pass filter	MicroTronics HPM10418
assorted cables and connectors	

Table 1. List of equipment used for LNA linearity test.

Setup

A block diagram of the test apparatus is shown in Figure 1. The equipment was arranged such that the "victim" receiver's antenna was pointed between the sinewave generator and TM-UWB transmit antennas. The two transmit antennas were placed closely together but separated enough to limit mutual loading. The 3 m spacing was selected since this is a standard distance for testing emissions. The tests were performed in an open room with the antennas 1.57 m from the floor.

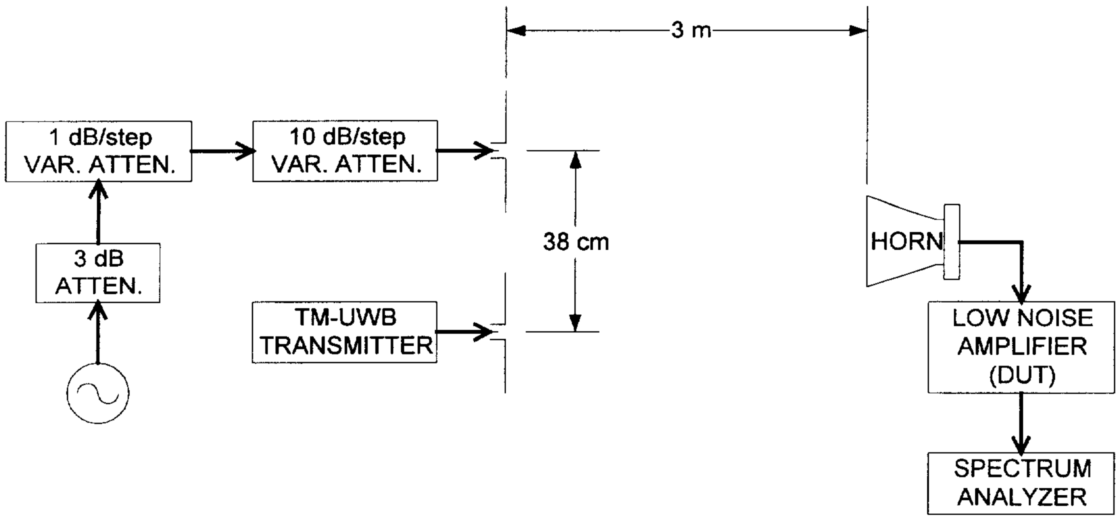


Figure 1. Block diagram of LNA linearity test apparatus.

The attenuators on the sinewave generator serve two purposes. The fixed attenuator is used to reduce reflection between the generator and the antenna, which could affect the generator performance. Any reflections from the antenna are reduced by 6 dB due to the two way path through the fixed attenuator. The variable attenuators provide the means to test the linearity of the amplifiers while keeping the ambient signals, including the TM-UWB emissions, constant.

Settings and Specifications

The configuration of the equipment used to perform a test is as important as the types of equipment. The equipment settings and some of the key specifications are listed in Table 2. The sinewave generator represents the desired transmitter for the "victim" receiver. The generator's amplitude was limited by the highest output level of the tracking generator, however this limit seems suitable because it is below the 1 dB saturation point of the devices under test (DUTs), yet is significantly larger than the envelop of TM-UWB signal (Section E). The sinewave was set to be in the middle of the TM-UWB bandwidth, 1.3 GHz, where the effects of the emissions should be maximized.

Description	Value
Hewlett Packard 8595 tracking generator	
sinewave transmit power	-8.45 dB_m
frequency	1.299 GHz
Time Domain 1.3 GHz UWB dipoles	
center frequency	1.3 GHz
gain at center frequency	2 dB_i
bandwidth	1.3 GHz
Time Domain 3002-1 Gemini	
transmit power	3.7 dB_m ($f > 1$ GHz)
pulse repetition rate	5 MHz
Electro-Metrics RGA-30	Section A
Hewlett Packard 8447D	Section B
Miteq AMF-2D-005060-18-13P	Section C
Miteq AFS3-00100400-28-10P-4	Section D
Hewlett Packard 8590B	
detector type	Peak
resolution bandwidth	100 kHz
video bandwidth	30 kHz
video averaging	10
span	2 MHz
attenuation	30 dB

Table 2. Equipment settings and key specifications used for the experiment.

The antennas were selected to prevent bias of one transmitter over the other and provide a well controlled test. Both transmitters used the same type of antennas, UWB dipoles, while the receiver used a calibrated ridge waveguide horn antenna.

The power level of the TM-UWB transmitter is set higher than would be anticipated under Part 15 operation. Assuming the radiated emissions were not adjusted for pulse desensitization, this transmitter would exceed the Part-15 limits by approximately 3 dB. This additional power makes the experiment results more conservative.

The goal of selecting the LNA's was to find representative sample of the first amplifiers used by wideband microwave receivers. The three amplifiers used were readily available in the TDC laboratory. All three were tested to reduce the potential that one amplifier just happened to perform differently from the others in terms of interference. These amplifiers all have very large bandwidths to maximize the intercepted UWB signal. An Internet search of several microwave communication amplifier suppliers was also performed. The amplifiers tested did not appear to have specifications that seemed out of the ordinary when compared with the typical off-the-shelf amplifiers.

The spectrum analyzer, acting as a "victim receiver", has a number of control settings. A peak detector was used to accentuate any short distortion effects caused by the TM-UWB emissions. The desired goal for the resolution bandwidth was to minimize its setting to observe the power relationship of a narrow signal even though it is going through a very wideband amplifier. The resolution bandwidth did have to be widened because of instability between the transmitter's and the receiver's oscillators. The video bandwidth was left on auto, so it used a bandwidth a third of the resolution bandwidth. Video averaging was used to simplify reading the data points. The peak values read by the spectrum analyzer's markers varied somewhat when video averaging was not used. The averaging made the $1/10^{th}$ of a dB reading possible but did not appear to have altered the data in any manner other than improving the SNR of the measurements. The span was selected merely on the basis of the need to observe the entire spectrum where the signal may appear to exist due to instabilities of the transmitters' and receivers' oscillators. This span also provides a means to observe the spectral envelop of both the sinewave and TM-UWB signals (Section E), even though the narrow band transmission has been distorted. Finally, the internal attenuation of the spectrum analyzer is used to guarantee that the amplified signal does not saturate the analyzer's LNA, which would void the experiment.

Procedure

<u>Linearity Measurement</u>

The procedure for measuring the linearity of the LNA's is described by the following;

1. The three DUT's or LNA's were tested using the same procedure.
2. Collect the equipment required to perform test, see Table 1.
3. Set-up the equipment the configuration as depicted in Figure 1.
4. Each DUT was tested using a series of measurements, one when the TM-UWB signal was turned off and another where the TM-UWB transmitter was turned on.
5. The variable attenuators were set to 0 dB. Note: the fixed attenuator was in place for the duration of the tests.
6. The largest value of the observed spectrum was then recorded.
7. The attenuation was then increased by 1 dB.
8. The last two steps were repeated until the attenuation had reached 20 dB.

9. The measured data was then plotted to show the linear behavior with respect to the attenuator, i.e., sinewave transmit power variation.

Power Measurement

The procedure for measuring the transmit power of the sinewave generator and TM-UWB transmitter was as follows:

1. Collect the equipment to perform test.
2. Calibrate the power meter as specified by the manufacturer.
3. Connect the power meter to the output of the sinewave generator.
4. Record measured transmit power sinewave transmitter.
5. Connect a 1 GHz high pass filter to the output of the TM-UWB transmitter. This filter is used to approximate the power that effectively radiates from the antenna structure. The antenna performs a significant amount of filtering. The high pass filter is necessary to prevent the low frequency components, that can not efficiently radiate from the UWB antenna, from producing misleading measurements.
6. Connect the power meter to the output of the 1 GHz high pass filter.
7. Record measured transmit power for the TM-UWB transmitter.

A secondary measurement was performed to verify that the power meter measurement of the UWB signal was accurate with the signal low duty cycle. This experiment was performed by using the variable attenuators and reducing the signal by 1 dB through 20 dB, 30 dB, and 40 dB. The measurements produced in the predicted results in all cases. This included the case when the measurement was performed without the 1 GHz high pass filter.

Data

The data collected in the procedure described previously is presented in Section E. The Section also contains several plots from the spectrum analyzer showing received signal. The measured data points were then plotted. The received powers versus the sinewave generator's attenuation, without the TM-UWB signal, are shown in Figure 2. The received powers versus the sinewave generator's attenuation in the presence of TM-UWB emissions are shown in Figure 3. The plotted data forms straight lines in all cases.

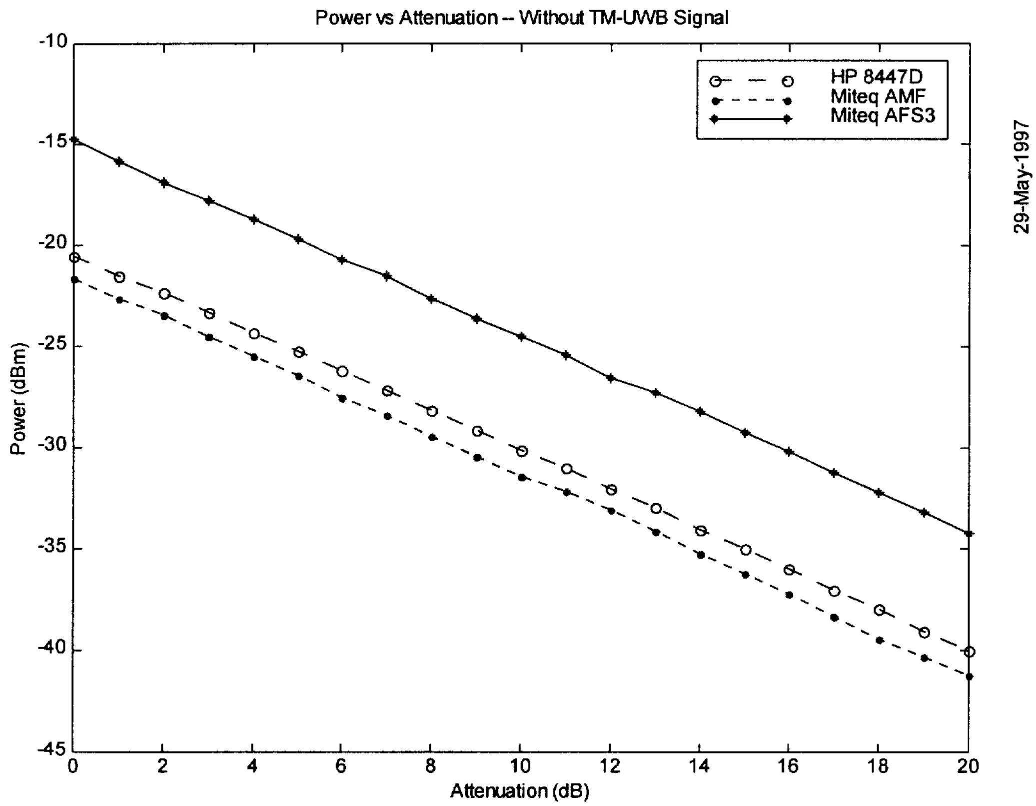


Figure 2. Received power from sinewave transmission only versus attenuation on the sinewave generator for three different low noise amplifiers.

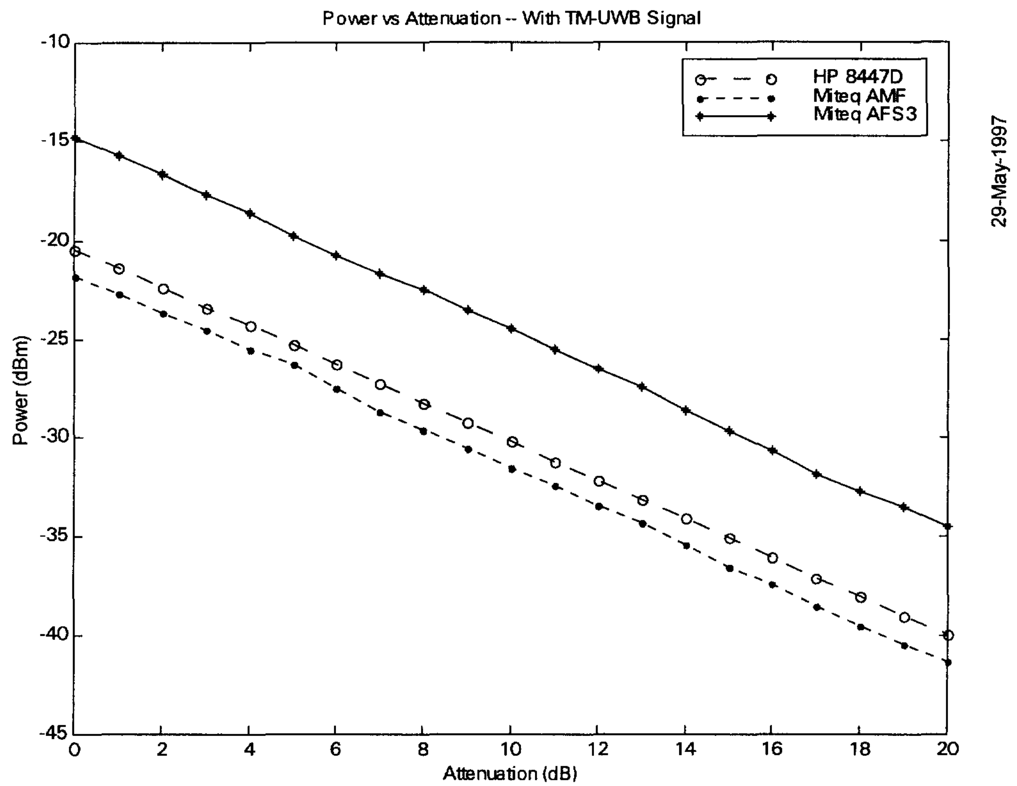


Figure 3. Received power from sinewave and TM-UWB transmissions versus attenuation on the sinewave generator for three different low noise amplifiers.

Results and Conclusion

An experiment was performed to demonstrate that the peak-envelop-power exhibited by time modulated ultra-wideband (TM-UWB) systems operating under FCC Part 15 regulations, such as those being developed by Time Domain., do not produce non-linear behavior in broadband amplifiers. Three amplifiers tested have specifications typical of microwave communication systems, except that their inputs were not filtered, to make them more susceptible to UWB emissions.

By monitoring the received signal from a magnitude controlled sinewave generator by itself and in the presence of TM-UWB emissions, the linear behavior of the amplifier under test can be determined. The plotted results clearly show the data forms straight lines within the margin of error of the test apparatus for all trials. This indicates that the amplifiers were linear for the sinewave, and remained so when the TM-UWB signal was being transmitted at power level consistent with Part 15 operation when it is not adjusted for pulse desensitization.

These results support the assertions that TM-UWB emissions are noise-like and do not require their radiated emission measurements to be adjusted for pulse desensitization.

Section A – Electro-Metrics RGA-30 Specification Sheet.
(Specifications have been copied from manufacturer's calibration data.)

GAIN AND ANTENNA FACTORS
FOR
DOUBLE RIDGE GUIDE HORN ANTENNA

ELECTRO-METRICS
MODEL NUMBER RGA-30
S/N 2455

1 METER CALIBRATION

FREQUENCY (MHz)	ANTENNA FACTOR (dB)	GAIN NUMERIC	GAIN dB
200	11.2	3.23	5.1
300	12.8	5.01	7.0
400	13.8	7.08	8.5
500	16.4	5.98	7.8
600	17.6	6.62	8.2
700	18.1	7.99	9.0
800	18.6	9.35	9.7
900	20.2	8.16	9.1
1000	22.5	5.86	7.7
1100	22.5	7.23	8.6
1200	23.3	7.11	8.5
1300	23.5	7.88	9.0
1400	24.5	7.39	8.7
1500	25.7	6.36	8.0
1600	25.0	8.55	9.3
1700	25.7	8.19	9.1
1800	25.1	10.42	10.2
1900	27.0	7.52	8.8
2000	31.7	2.84	4.5

SPECIFICATION COMPLIANCE TESTING FACTOR (1 METER SPACING)
TO BE ADDED TO RECEIVER METER READING IN dBuV TO CONVERT TO
FIELD INTENSITY IN dBuV/METER.
CALIBRATION PER ARP 958 METHODOLOGY.

Section B - Hewlett Packard 8447D Low Noise Amplifier Specification Sheet.

(Specifications have been copied from manufacturer's catalog.)

AMPLIFIERS
RF Amplifiers
HP 8347A, 8447A/D/E/F 395

HP 8447D

HP 8447 Series Amplifiers

These low-noise, high-gain amplifiers have many general-purpose uses. They improve the sensitivity of spectrum analyzers, counters, RF voltmeters, EMI meters, power meters, and other devices. They will also increase the maximum power available from a signal generator or sweeper.

Standard connectors are BNC (f). Other options are:
Option 010: Single-Channel Amplifier, N (f) Connectors
Option 001: Dual-Channel Amplifier, BNC (f) Connectors
Option 011: Dual-Channel Amplifier, N (f) Connectors

Dual-channel, 50 Ω (nominal) amplifiers are ideal for dual-channel systems such as oscilloscopes or network analyzers. Channels may also be cascaded for increased small-signal gain.

General Specifications (all models)

Weight: Net, 1.56 kg (3.4 lb); shipping, 2.3 kg (5.1 lb)
Size: 130 mm W × 85.8 mm H × 216 mm D (5.1 in × 3.4 in × 8.5 in)
Power: 110 or 230 Vac + 10%, 48 to 440 Hz, 15 W

Ordering Information

Ordering Information	Price
HP 8447A Preamplifier	$1,600
HP 8447D Preamplifier	$1,700 ☎
HP 8447E Power Amplifier	$1,925
HP 8447F Preamplifier-Power Amplifier	$2,790

☎ For off-the-shelf shipment, call 800-452-4844.

Specifications Summary

Note: HP 8447F is HP 8447D and 8447E combined in a single package.

	HP 8447A Preamp	HP 8447D Preamp	HP 8447E Power amp
Frequency range	0.1 to 400 MHz	100 kHz to 1.3 GHz	100 kHz to 1.3 GHz
Typical 3 dB bandwidth	50 kHz to 700 MHz	75 kHz to 1.7 GHz	75 kHz to 1.4 GHz
Gain (mean, per channel)	20 dB ± 1.0 dB at 10 MHz (20° to 30° C)	> 25 dB (20° to 30° C)	22 dB ± 1.5 dB (20° to 30° C)
Gain flatness across full frequency range	± 1.5 dB (0° to 55° C) ± 0.7 dB (20° to 30° C) characteristic	± 1.5 dB	± 1.5 dB
Noise figure	<7 dB	<8.5 dB	<11 dB typical
Output power for 1 dB gain compression	> +6 dBm	> +7 dBm typical	> +12.5 dBm 100 MHz to 1 GHz
Harmonic distortion	−32 dB for 0 dBm output	−30 dB for 0 dBm output (typical)	−30 dB for 0 dBm output
Output for < −60 dB harmonic distortion	−25 dBm (characteristic)	−30 dBm	−20 dBm
VSWR	<1.7	<2.0 input <2.2 output 1 to 1300 MHz	<2.2 input <2.5 output 1 to 1300 MHz
Reverse isolation	> 30 dB	> 40 dB	> 40 dB
Maximum dc voltage input	± 10 V	± 10 V	± 10 V
Options available	001	001, 010, 011	010
Option prices	+ $725	+ $775, $105, $1,190	+ $125

Section C - Miteq AMF-2D-005060-18-13P Low Noise Amplifier Specification Sheet.

(Specifications have been copied from manufacturer's data sheet.)

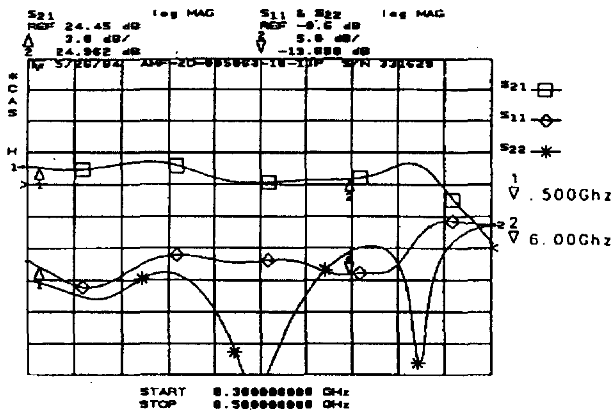
MITEQ

Project P50153
Internal Transfer N/A
Customer P/N N/A
Model AMF-2D-005060-18-13P
Serial No. 331629

SPECIFICATIONS

Frequency	0.5 – 6.0 GHz	Power Output at 1dB Compression	+13.0 dBm Min.
Gain	23.0 dB Min.	Voltage	+15 V
Gain Flatness	+/– 1.5 dB Max.	Measured current	99 mA
VSWR Input/Output	2.0:1 Max.		
Noise Figure	1.8 dB Max.		

TEST DATA

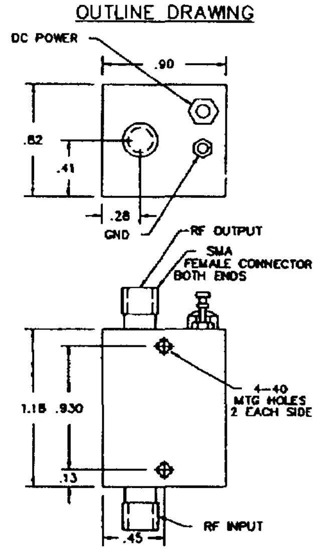


TEST DATA SUMMARY

Max Gain	26.60 dB
Min Gain	24.62 dB
Gain Flatness	1.98 dB
Max Noise Figure	1.70 dB
Min Noise Figure	1.16 dB
Max Po 1dB Comp.	14.94 dBm
Min Po 1dB Comp.	13.13 dBm
Max Input VSWR	1.82
Max Output VSWR	1.86

Freq. (GHz)	N. F. (dB)	Po (dBm) 1dB Comp.	Freq. (GHz)	N. F. (dB)	Po (dBm) 1dB Comp.
.500	1.16	13.59			
1.00	1.36	13.61			
1.50	1.50	13.90			
2.00	1.70	14.69			
2.50	1.44	14.87			
3.00	1.47	14.94			
3.50	1.44	14.49			
4.00	1.44	13.92			
4.50	1.67	13.73			
5.00	1.67	13.73			
5.50	1.64	13.56			
6.00	1.62	13.13			

OUTLINE DRAWING



Tested By Greg P. Bulls Date 5/26/94

MITEQ INC. • 100 Davids Drive • Hauppauge, New York 11788-2086 • Tel. (516)436-7400

Section D - Miteq AFS3-00100400-28-10P-4 Low Noise Amplifier Specification Sheet.

(Specifications have been copied from manufacturer's data sheet.)

MITEQ

100 Davids Drive, Hauppauge, N.Y. 11788
TEL: (516) 436-7400
FAX: 516-436-7430

PROJECT No:	P54970
MODEL No:	AFS3-00100400-28-10P-4
SERIAL No:	359209
CUSTOMER:	TIME DOMAIN SYSTEMS
P.O. No:	16752

IMPORTANT - MUST USE HEAT SINK IF CASE TEMPERATURE EXCEEDS 70°C

SPECIFICATIONS AT +23°C:			
FREQUENCY:	.10 to 4.0 GHz	OUTPUT POWER @1dB GAIN COMPRESSION	+10 dBm
MIN. GAIN:	28 dB	VOLTAGE:	+15 VOLTS
MAX.GAIN FLATNESS:	+/- 1.25 dB	MEASURED CURRENT:	97 mA
MAX. VSWR INPUT:	2 :1	MAX. NOISE FIGURE:	2.8 dB
MAX. VSWR OUTPUT:	2 :1	HOUSING No:	112225

NOTE: TEST DATA TAKEN WITH CASE TEMP. OF +23° C

FREQUENCY (GHz)	GAIN (dB)	VSWR IN	VSWR OUT	NOISE FIGURE (dB)	OUTPUT POWER @1dB GAIN COMPRESSION
.10	33.6	1.58	1.43	1.40	+11
.50	33.4	1.43	1.15	.93	+11
1.0	34.5	1.43	1.33	1.02	+12
2.0	33.4	1.58	1.58	1.17	+14
3.0	33.1	1.58	1.58	1.06	+15
4.0	32.8	1.78	1.38	1.09	+15

COMMENTS: NOISE FIGURE INCREASES BELOW 500 MHZ. IP_3 ~ 20dBm
Max input ~ 15dBm

TESTED BY: Gerald Waldman (GERALD WALDMAN) DATE: 03/20/95 [illegible] – Tabulated Data.

	Hewlett Packard 8447D		Miteq AMF-2D-005060-18-13P		Miteq AFS3-00100400-28-10P-4	
Attenuation (dB)	P_r w/o UWB (dBm)	P_r with UWB (dBm)	P_r w/o UWB (dBm)	P_r with UWB (dBm)	P_r w/o UWB (dBm)	P_r with UWB (dBm)
0	-20.6	-20.4	-21.7	-21.8	-14.8	-14.8
1	-21.6	-21.4	-22.7	-22.7	-15.8	-15.8
2	-22.3	-22.4	-23.5	-23.6	-16.8	-16.7
3	-23.4	-23.4	-24.5	-24.6	-17.8	-17.6
4	-24.3	-24.3	-25.5	-25.5	-18.7	-18.6
5	-25.2	-25.3	-26.5	-26.3	-19.7	-19.8
6	-26.2	-26.2	-27.5	-27.5	-20.7	-20.8
7	-27.2	-27.2	-28.4	-28.7	-21.6	-21.7
8	-28.2	-28.3	-29.5	-29.6	-22.7	-22.5
9	-29.1	-29.3	-30.4	-30.6	-23.6	-23.6
10	-30.1	-30.1	-31.4	-31.5	-24.5	-24.5
11	-31.1	-31.2	-32.2	-32.4	-25.4	-25.6
12	-32.0	-32.1	-33.1	-33.5	-26.5	-26.5
13	-33.0	-33.1	-34.1	-34.3	-27.3	-27.5
14	-34.0	-34.1	-35.2	-35.4	-28.2	-28.6
15	-35.0	-35.1	-36.2	-36.5	-29.3	-29.7
16	-36.0	-36.0	-37.2	-37.4	-30.2	-30.7
17	-37.0	-37.1	-38.3	-38.5	-31.2	-31.8
18	-38.0	-38.0	-39.4	-39.5	-32.3	-32.7
19	-39.0	-39.0	-40.3	-40.4	-33.2	-33.5
20	-40.0	-40.0	-41.2	-41.3	-34.2	-34.5
Plot →	**I**	**II**	**III**	**IV**	**V**	**VI**

Table 3. Recorded data points for amplifier linearity trials.

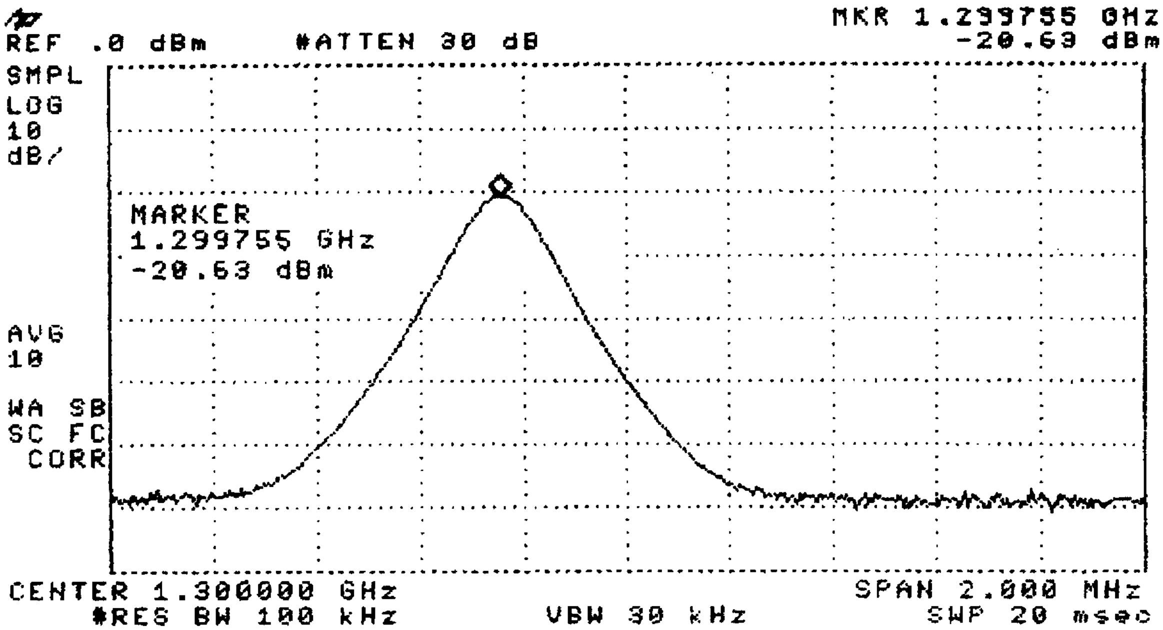


Figure 4. (I) Spectrum analyzer plot of sinewave generator emission with 0 dB attenuation when using Hewlett Packard 8447D Low Noise Amplifier.

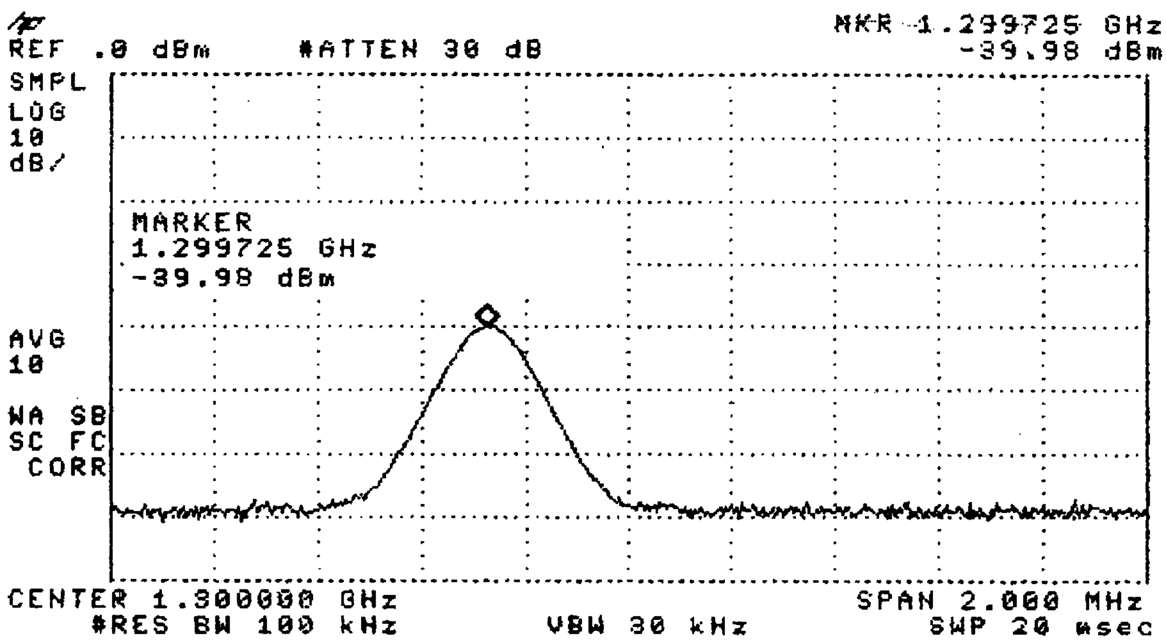


Figure 5. (I) Spectrum analyzer plot of sinewave generator emission with 20 dB attenuation when using Hewlett Packard 8447D Low Noise Amplifier.

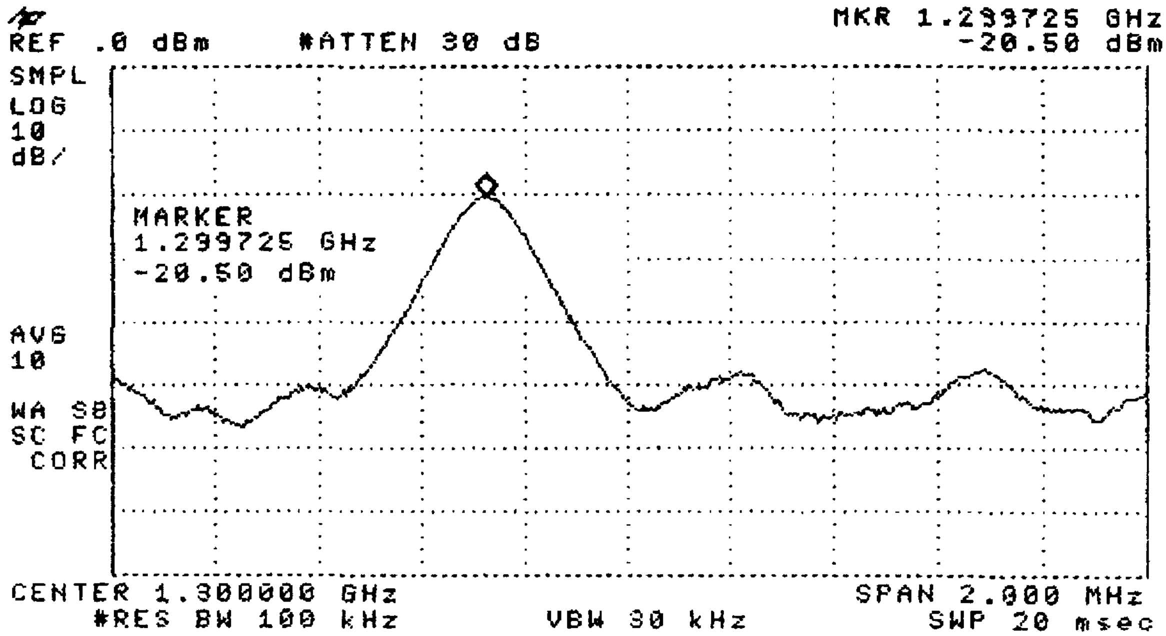


Figure 6. (II) Spectrum analyzer plot of sinewave generator emission with 0 dB attenuation and TM-UWB emission when using Hewlett Packard 8447D Low Noise Amplifier.

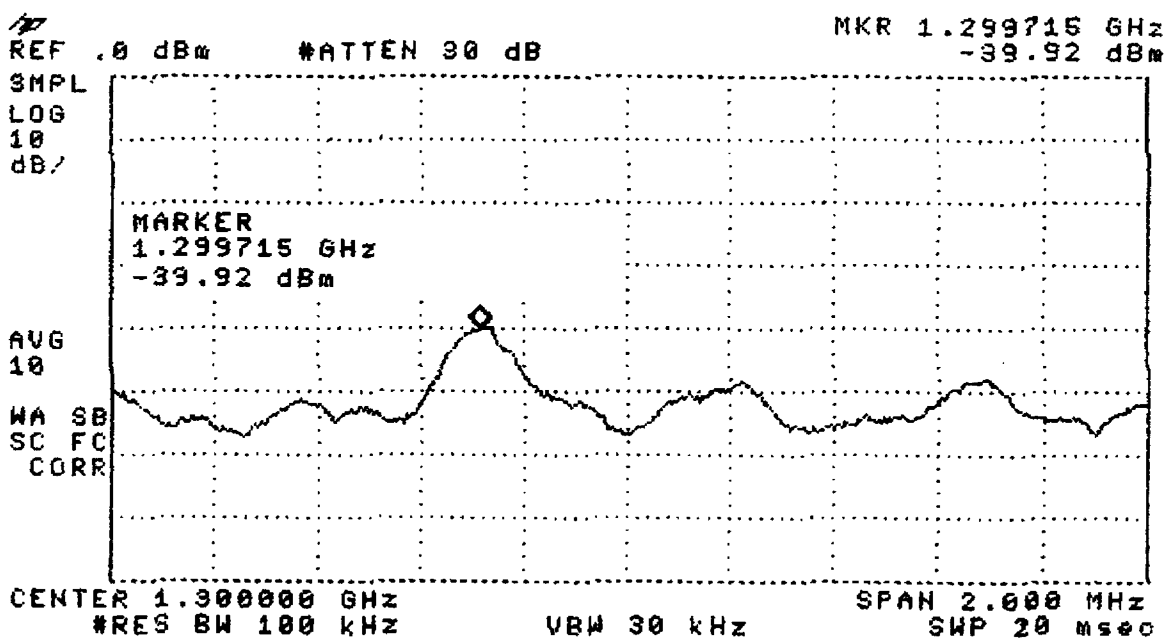


Figure 7. (II) Spectrum analyzer plot of sinewave generator with 20 dB attenuation and TM-UWB emission when using Hewlett Packard 8447D Low Noise Amplifier.

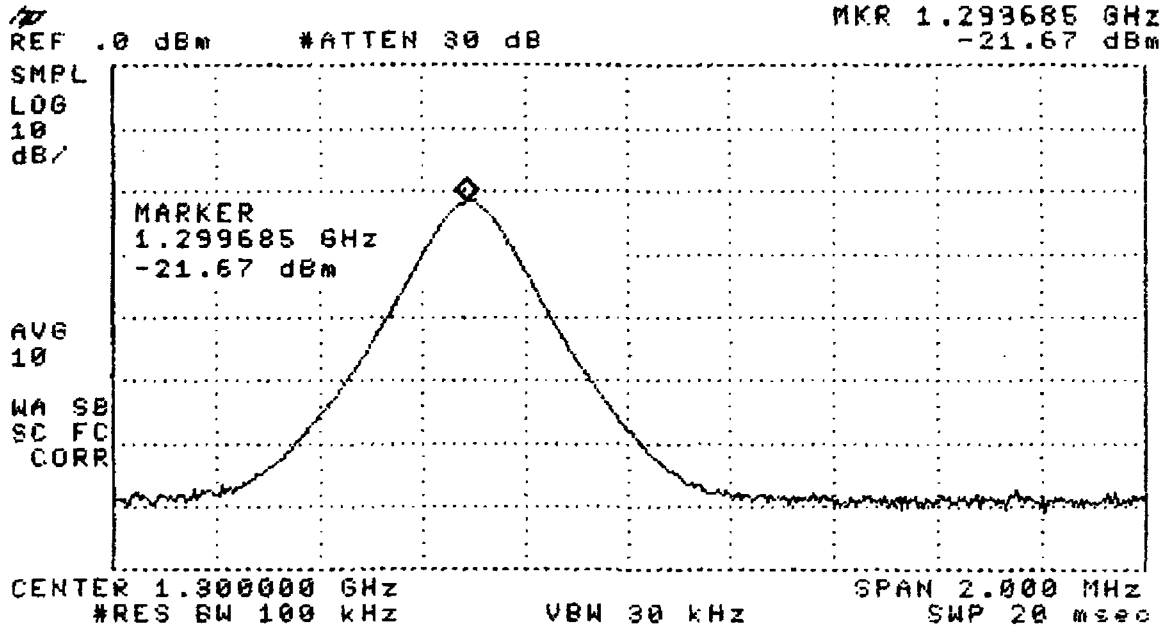


Figure 8. (III) Spectrum analyzer plot of sinewave generator emission with 0 dB attenuation when using Miteq AMF-2D-005060-18-13P Low Noise Amplifier.

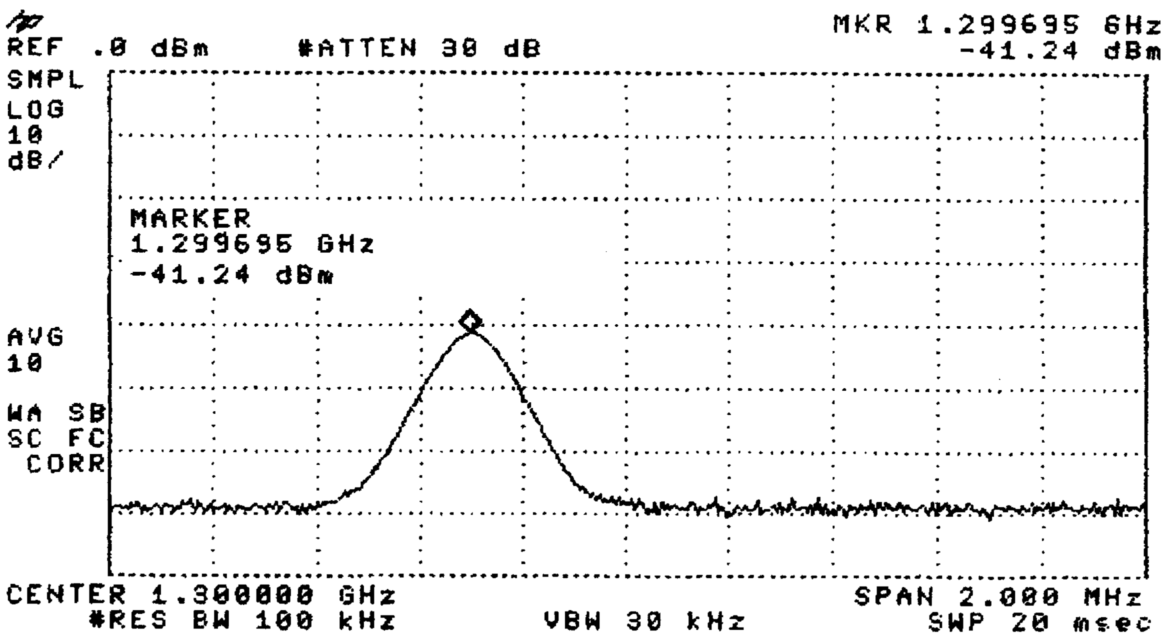


Figure 9. (III) Spectrum analyzer plot of sinewave generator emission with 20 dB attenuation when using Miteq AMF-2D-005060-18-13P Low Noise Amplifier.

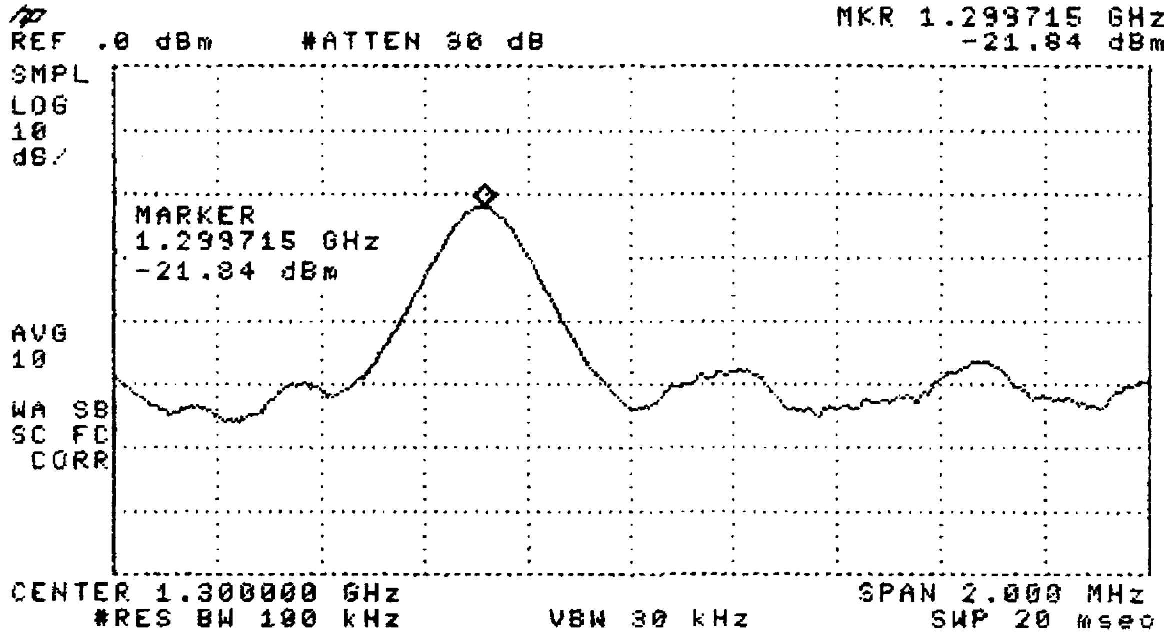


Figure 10. (IV) Spectrum analyzer plot of sinewave generator emission with 0 dB attenuation and TM-UWB emission when using Miteq AMF-2D-005060-18-13P Low Noise Amplifier.

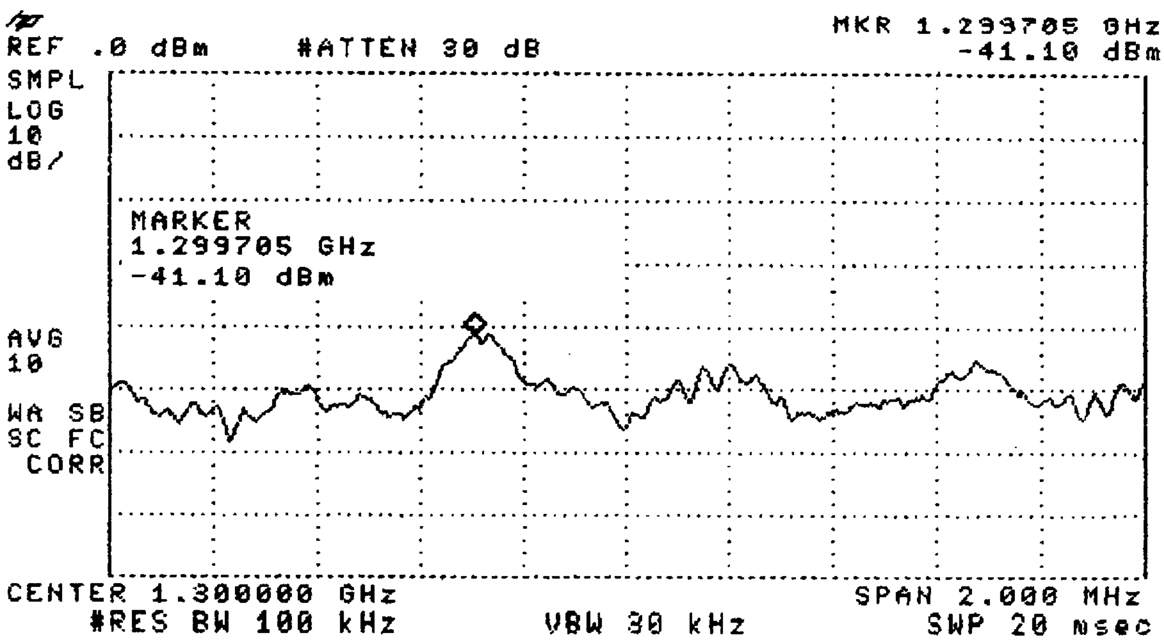


Figure 11. (IV) Spectrum analyzer plot of sinewave generator with 20 dB attenuation and TM-UWB emission when using Miteq AMF-2D-005060-18-13P Low Noise Amplifier.

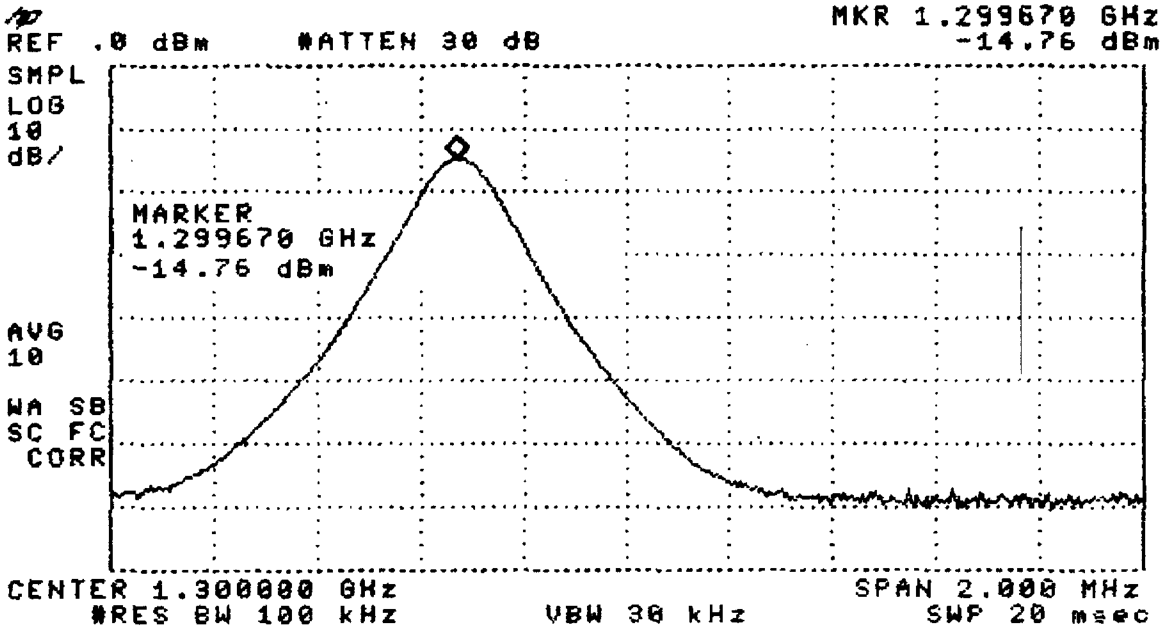


Figure 12. (V) Spectrum analyzer plot of sinewave generator emission with 0 dB attenuation when using Miteq AFS3-00100400-28-10P-4 Low Noise Amplifier.

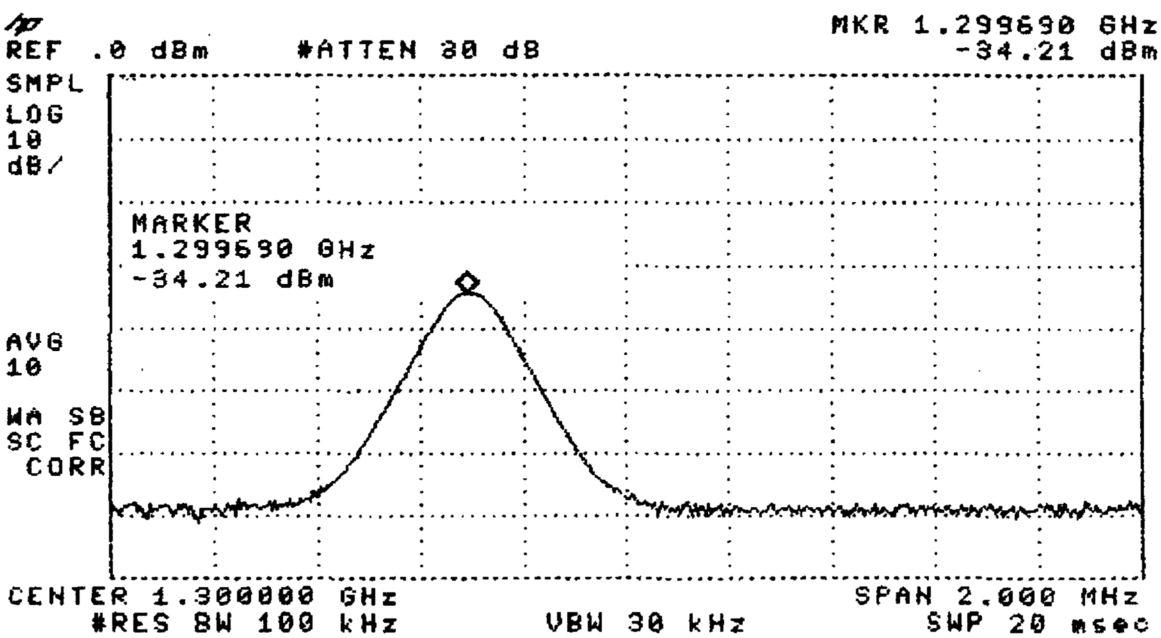


Figure 13. (V) Spectrum analyzer plot of sinewave generator emission with 20 dB attenuation when using Miteq AFS3-00100400-28-10P-4 Low Noise Amplifier.

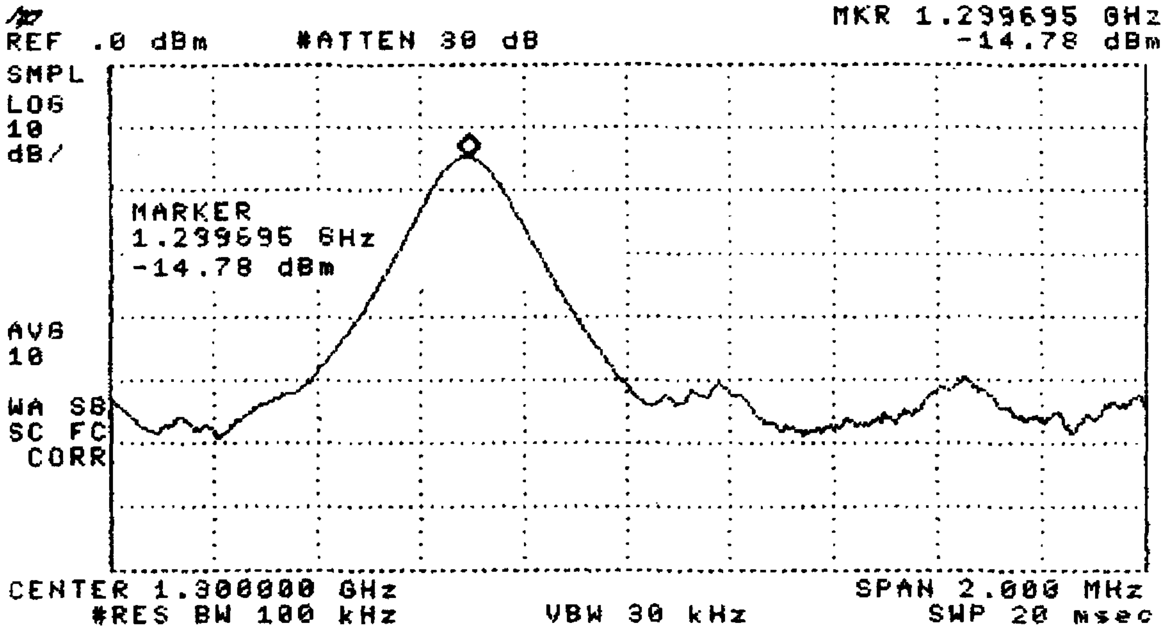


Figure 14. (VI) Spectrum analyzer plot of sinewave generator emission with 0 dB attenuation and TM-UWB emission when using Miteq AFS3-00100400-28-10P-4 Low Noise Amplifier.

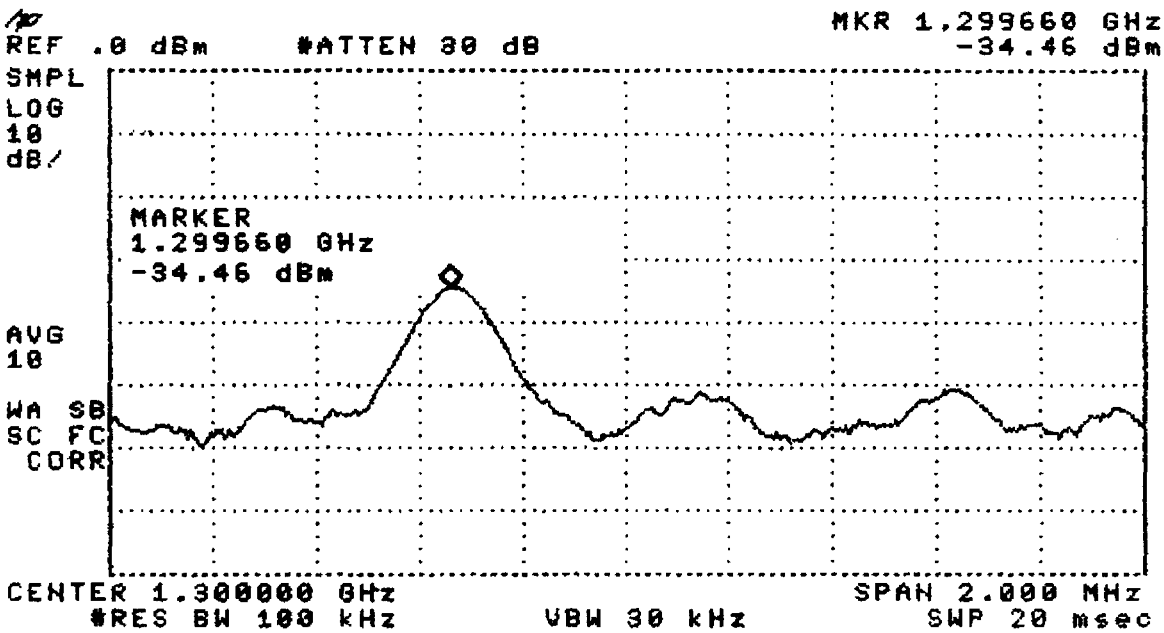


Figure 15.. (VI) Spectrum analyzer plot of sinewave generator with 20 dB attenuation and TM-UWB emission when using Miteq AFS3-00100400-28-10P-4 Low Noise Amplifier.